(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 825 733 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
25.02.1998 Bulletin 1998/09

(51) Int Cl.6: H04B 10/155

(21) Application number: 97306244.1

(22) Date of filing: 18.08.1997

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE

(30) Priority: 16.08.1996 JP 216432/96
14.01.1997 JP 4203/97

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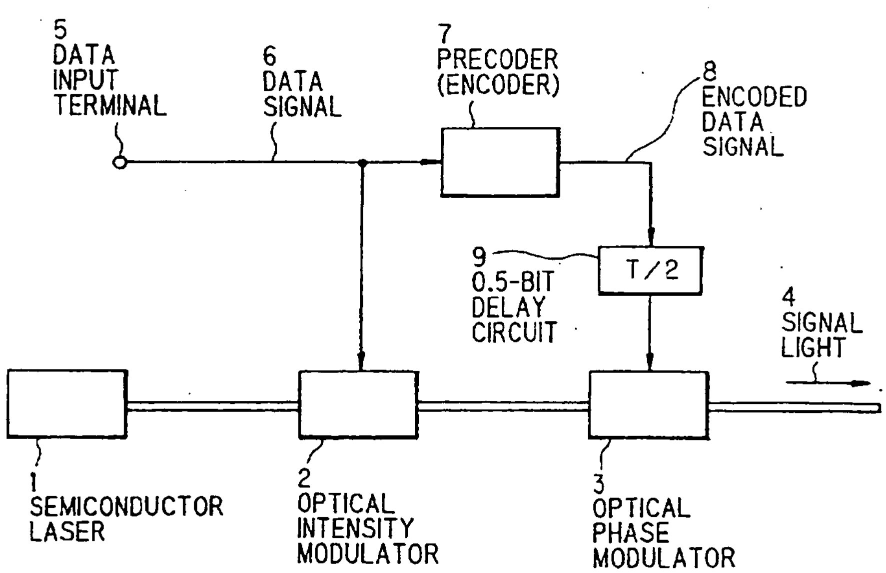
(54) Method of generating duobinary signal and optical transmitter using the same method

(57) Disclosed is a method for generating a duobinary signal which has the step of: modulating individually an intensity and a phase of carrier wave. Also disclosed is a duobinary-manner optical transmitter which has: a laser device which outputs signal light; an optical intensity modulator which intensity-modulates the signal light according to a first data signal generated by dividing a data signal into two signals; a precoder which inputs a second data signal generated by dividing the date signal into two signals; and an optical phase modulator which phase-modulates the intensity-modulated signal light according to a signal which is obtained delaying 0.5 bit an output signal of the precoder.

FIG.8



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Description

This invention relates to a method of generating a duobinary signal and an optical transmitter using the same method.

Recently, an optical duobinary technique has attracted attention as an optical transmission manner which can overcome the waveform deterioration due to a chromatic dispersion. The duobinary technique itself has been researched for a long time and its theory system was established in the time of pulse communication with a coaxial cable. The duobinary technique is that a signal bandwidth(spectrum width) is reduced to less than 1/2 by mapping a binary data signal to be transmitted into a three-level signal with a redundancy in the amplitude direction. It has a merit that the waveform deterioration due to a dispersion etc. is difficult to happen since the spectrum width is narrowed. However, it had never attracted attention in high-speed optical communication since, in the receiver, a receiving circuit with a linearity is required to handle the three-level signal and a decoder for decoding the original binary data signal from the three-level signal is necessary.

A. J. Price et al.,"210 km Repeaterless 10 Gb/s Transmission Experiment Through Nondispersion-Shifted Fiber Using Partial Response Scheme", IEEE PHOTONICS TECHNOLOGY LETTERS, Vol.7, No.10, pp.1219-1221(1995) reports an optical duobinary technique where a redundancy is given to optical phase.

The optical transmitter used in this optical duobinary technique is shown in FIG.1. A binary data signal is passed through a low-pass filter, which is ideally a cosine roll-off filter, with a bandwidth of about 0.25 times a clock frequency. Due to the excessive limitation of bandwidth, the interference between codes is occurred to convert the binary data signal into a three-level data signal. Similarly, a binary inverted data signal is converted into a three-level data signal. Then, these signals are input with an amplitude equal to a half-wavelength voltage V_π to a push-pull optical intensity modulator. The push-pull optical intensity modulator is a Mach-Zehnder (MZ) interferometer with modulation terminals connected to both arms, where unnecessary chirp(phase variation) does not occur. In this technique, the bias voltage is so adjusted that a three-level signal(-1, 0, 1) corresponds to a mountain(ON), a valley(OFF) and a neighboring mountain(ON) in the voltage-extinction characteristic of the push-pull optical intensity modulator. As a result, when the amplitude and phase of light are represented by (A, Φ), the data signal is mapped into three states of (1, 0), (0, indefinite) and (1, π) to generate optical duobinary signal light. This three-level signal light can be, as it is, decoded into the binary signal composed of 1 and 0 since the phase information is deleted by square-law detection when the direct detection is conducted by an optical detector. This means that direct-detection optical receivers, which are widely used, can be used as it is. It is one of the reasons why the duobinary technique has attracted attention again.

Japanese patent application laid-open No. 8-139681(1996) discloses another optical duobinary system as shown in FIG.2. In this system, as shown in FIG.2, a binary transmission data signal 50 is converted into a three-level duobinary signal by a code converter 51. In the code converter 51, the code conversion is first conducted by a precoder 52 composed of an exclusive-OR circuit 26 and an 1-bit delay circuit 27, and then the duobinary signal is generated by a binary-to-three-level converter 53 composed of an 1-bit delay circuit 27 and an adder 54. The duobinary signal is divided into two signals, where the first signal divided is input through an amplitude adjusting circuit 55 and a bias adjusting circuit 56 to the first input terminal of an optical modulator 58 and the second signal divided is input through an inverter 57 and an amplitude adjusting circuit 55 to the second input terminal of the optical modulator 58. The optical modulator 58 is a Mach-Zehnder optical intensity modulator, where light from a light source 1 is modulated by applying the first and second signals to its two optical waveguides to generate the optical duobinary signal.

When the two electrical signals with an amplitude equal to a half-wavelength voltage(V_π) of the optical modulator 58 are input and the bias point of signal is set at a point (a) of transmission characteristics 59 of the modulator as shown in FIG.3, the middle value of the duobinary signal 60 is assigned to a minimum transmittance state and the minimum and maximum values thereof are assigned to maximum transmittance states, where the optical phase is inverted by 180 degree between the minimum and maximum values. As a result, the three levels of the electrical signal can be assigned to the optical three states, thereby narrowing the modulated light spectrum. Meanwhile, this system has a composition equivalent to the system in FIG.1 where the low-pass filters are replaced by the binary-to-three-level converter 53.

However, in the conventional methods, the driving amplifier of the modulator requires a linearity since the electrical signal for driving the optical modulator is three-level. On the other hand, the driving amplifier generally needs a high-output characteristic greater than 5Vp-p. Therefore, there is a problem that designing the circuit becomes very difficult since the linearity and the high-output characteristic are required therein.

Accordingly, it is an object of at least the preferred embodiments of the present invention to provide a method of generating a duobinary signal where an electrical signal for driving an optical modulator is binary.

It is a further such object to provide an optical transmitter where a binary electrical signal for driving an optical modulator is used to generate a duobinary signal.

According to the invention, a method of generating a duobinary signal, comprises the step of:

modulating individually an intensity and a phase of a carrier wave.

According to another aspect of the invention, a du-

obinary-type optical transmitter, comprises:
means for modulating individually an intensity and a phase of a carrier wave.

Another aspect of the present invention provides a duobinary-type optical transmitter, comprising a laser device for outputting a light signal, an optical intensity modulator for intensity-modulating said signal according to one of two data signals generated by dividing a data signal into two signals, a precoder for receiving the other of the two data signals, and an optical phase modulator for phase-modulating said intensity-modulated signal according to a signal obtained by delaying by 0.5 bit an output signal of said precoder.

According to another aspect of the invention, a duobinary-type optical transmitter comprises a precoder for receiving one of two data signals generated by dividing a data signal into two signals, a direct modulation phase shift keying encoder for delaying an output of said precoder by 0.5 bits, a laser device for outputting a light signal phase-modulated by modulating an injected current according to an output of said direct modulation phase shift keying encoder, and an optical intensity modulator for intensity-modulating said phase-modulated light signal according to the other of said two data signals.

According to another aspect of the invention, a method of generating a duobinary signal, comprises the steps of providing two carrier waves with an equal frequency, intensity-modulating individually the two carrier waves by first and second intensity modulators, and coupling the two intensity-modulated carrier waves so that the phase difference of said intensity-modulated carrier waves is π.

Another aspect of the present invention provides a duobinary-type optical transmitter comprising means for providing two carrier waves with an equal frequency, means for intensity-modulating individually said two carrier waves, and means for coupling said two intensity-modulated carrier waves so that the phase difference of said intensity-modulated carrier waves is π.

According to another aspect of the invention, a duobinary-type optical transmitter comprises:

a laser device for outputting a light signal;
an optical divider for dividing said signal into first and second light signals;
a first optical intensity modulator for receiving said first light signal;
a second optical intensity modulator for receiving said second light signal;
an optical coupler for coupling signals output from said first and second optical intensity modulator after phase-shifting at least one of said output signals so as to give a phase difference of π between said output signals of said first and second optical intensity modulators; and
a precoder for receiving a data signal;
wherein said first optical intensity modulator is driven by a first encoded signal generated by dividing an encoded signal output from said precoder into two signals, and said second optical intensity modulator is driven by a signal which is obtained by delaying by 1 bit a second encoded signal generated by dividing said encoded signal into said two signals, and inverting the value of the second encoded signal.

In a preferred embodiment, a duobinary-manner optical transmitter comprises:

a laser device which outputs signal light;
an optical intensity modulator which intensity-modulates the signal light according to a first data signal generated by dividing a data signal into two signals;
a precoder which inputs a second data signal generated by dividing the data signal into two signals; and
an optical phase modulator which phase-modulates the intensity-modulated signal light according to a signal which is obtained delaying 0.5 bit an output signal of the precoder;
wherein a waveform of the signal light is varied by changing an operating point of the optical intensity modulator.

In another preferred embodiment, a duobinary-manner optical transmitter, comprises:

a laser device which outputs signal light;
an optical intensity modulator which intensity-modulates the signal light according to a first data signal generated by dividing a data signal into two signals;
a precoder which inputs a second data signal generated by dividing the data signal into two signals; and
an optical phase modulator which phase-modulates the intensity-modulated signal light according to a signal which is obtained delaying 0.5 bit an output signal of the precoder;
wherein a waveform of the first data signal is varied through a non-linear electric circuit.

According to another aspect of the invention, a method of generating a duobinary signal, comprises the step of:

modulating individually an intensity and a polarization of a carrier wave.

According to another aspect of the present invention a duobinary-type optical transmitter comprising means for modulating individually an intensity and a polarization of a carrier wave.

According to another aspect of the invention, a duobinary-type optical transmitter, comprises:

a laser device for outputting signal light;
an optical intensity modulator for intensity-modulat-

ing the signal light according to a first data signal generated by dividing a data signal into two signals;
a precoder for receiving a second data signal generated by dividing the data signal into two signals; and
an optical polarization modulator for polarization-modulating the intensity-modulated signal light according to a signal obtained by delaying by 0.5 bit an output signal of the precoder.

In the invention, an intensity modulator and a phase modulator are cascade-connected, and the amplitude (or intensity) and phase of signal light are individually modulated. Meanwhile, an intensity modulation signal and a phase modulation signal are input to the intensity modulator and phase modulator, respectively, while having predetermined conversion and phase relations. The conversion and phase relations will be explained below. FIG.4 shows calculation results of the amplitude and phase of optical duobinary signal light modulated by a conventional three-level signal. As shown in FIG. 4, in the optical duobinary signal light, the phase is inverted from 0 to π or from π to 0 at a point where the amplitude is 0. The phase inversion occurs at the middle point of a 1 time slot. The phase does not change when the amplitude is 1. The characteristic that " the phase is inverted at a point where the amplitude is 0 " gives the characteristics of optical duobinary manner that have a narrowed optical spectrum and a high durability against dispersion.

When a data signal is transmitted carrying on an optical amplitude(or intensity) and is directly detected by an optical receiver to get the data signal, only the phase modulation signal needs to be encoded by a precoder(encoder). The rule of the encoding is, as described earlier, that " the phase modulation signal is inverted when the intensity modulation signal is 0". This can be easily achieved by EX-NOR(inverted output of exclusive "or") and a 1-bit delay circuit, as shown in FIG. 9. The precoder uses an output value 1 bit before, therefore the output is inverted depending on an initial output value. However, there is no problem because an absolute optical phase has no meaning for optical duobinary signal light. After delaying 0.5 bit the phase modulation signal to the intensity modulation signal, the intensity-modulated signal light is phase-modulated($0 - \pi$). Thereby, the optical duobinary signal light can be generated. In such cascade modulation, any one of the optical phase modulator and the optical intensity modulator may be placed at the first.

Also, two lights with an equal frequency may be provided by, for example, dividing signal light into two lights, then turning OFF(or ON) either of the two lights or both of them by two optical intensity modulators, thereafter coupling them to give a phase difference of π between the outputs from the two optical intensity modulators. As a result, the data signal can be mapped into three optical states as described earlier to generate optical duobinary signal light(parallel type). In this case, a parallel-type precoder is necessary for the input data signal in addition to the above-mentioned precoder. The parallel-type precoder can be, as shown in FIGS.20 and 21, composed of a simple circuit using a 1-bit delay circuit and an inverter.

Also, in the invention, by properly setting the optical intensity modulation waveform, modulated light closer to that in the optical duobinary modulation manner using the three-level signal can be obtained. In an ideal optical duobinary waveform, the cross point is biased upward as shown in FIG.5A, where the optical spectrum has very small high-frequency components as shown in FIG. 5B. To suppress the high-frequency components, the invention approaches the ideal optical duobinary by using a non-linear modulation characteristic of the optical intensity modulator or an electric circuit with a non-linear input characteristic. When a signal 62 is input as shown in FIG. 6A, the obtained modulation light spectrum has high-frequency components to be remained as shown in FIG.7A. On the contrary, when a signal 64 is input shifting the bias value, the output optical waveform 65, which is biased to the side of optical transmission, becomes closer to the ideal duobinary waveform, and the high-frequency components can also be suppressed as shown in FIG.7B.

On the other hand, in the composition of cascade-connected intensity modulator and phase modulator, when the main axis direction of polarization of output signal light is supplied to be 45° to the optical axis of the phase modulator, only the signal light component in the optical axis direction is phase-modulated. Therefore the polarization of signal light can be modulated according to phase modulation. As a result, the spectrum of the signal light is not so narrowed, but the polarization-modulated duobinary signal can be generated.

Preferred features of the present invention will now be described, purely by way of example only, with reference to the accompanying drawings, in which:-

FIG.1 is a block diagram showing a conventional optical-duobinary-manner optical transmitter,
FIG.2 is a block diagram showing another conventional optical-duobinary-manner optical transmitter,
FIG.3 is a diagram showing the setting of an operating point of LN modulator,
FIG.4 is a diagram showing the calculation results of amplitude and phase of optical duobinary signal light generated by a conventional method,
FIGS.5A and 5B are diagrams showing an ideal duobinary signal waveform and its spectrum,
FIGS.6A and 6B are diagrams showing the setting of two kinds of bias points in optical intensity modulation,
FIGS.7A and 7B are diagrams showing the optical spectra to the two kinds of bias point,
FIG.8 is a block diagram showing an optical transmitter in a first preferred embodiment according to

the invention,

FIG.9 is diagrams showing a circuit composition of a precoder 7 in FIG.8 and an input-output logic table therein,

FIGS.10A to 10D are diagrams showing the relation among the input and output of the precoder 7 and the amplitude and phase of signal light 4,

FIG.11 is a block diagram showing an optical transmitter in a second preferred embodiment according to the invention,

FIG.12 is a block diagram showing an optical transmitter in a third preferred embodiment according to the invention,

FIG.13 is a block diagram showing an optical transmitter in a fourth preferred embodiment according to the invention,

FIG.14 is a diagram showing a waveform change by a waveform equalizer 18 in FIG.13,

FIG.15 is a block diagram showing an optical transmitter in a fifth preferred embodiment according to the invention,

FIG.16 is a block diagram showing an optical transmitter in a sixth preferred embodiment according to the invention,

FIG.17 is a block diagram showing an optical transmitter in a seventh preferred embodiment according to the invention,

FIG.18 is a block diagram showing an optical transmitter in an eighth preferred embodiment according to the invention,

FIG.19 is a diagram showing an input-output logic table of a parallel-type precoder 39 in FIG.18,

FIG.20 is a diagram showing a first circuit composition of the precoder 39,

FIG.21 is a diagram showing a second circuit composition of the precoder 39,

FIG.22 is a block diagram showing an optical transmitter in a ninth preferred embodiment according to the invention,

FIG.23 is a block diagram showing an optical transmitter in a tenth preferred embodiment according to the invention,

FIGS.24A and 24B are diagrams showing an optical spectrum and a modulated light waveform in the case that optical intensity modulation in the tenth embodiment is conducted at a conventional bias point,

FIGS.25A and 25B are diagrams showing an optical spectrum and a modulated light waveform in the case that optical intensity modulation in the tenth embodiment is conducted at a shifted bias point,

FIG.26 is a block diagram showing an optical transmitter in an eleventh preferred embodiment according to the invention,

FIG.27 is a block diagram showing an optical transmitter in a twelfth preferred embodiment according to the invention,

FIG.28 is a diagram showing an input-output characteristic of a saturation amplifier in FIG.27,

FIGS.29A to 29C are diagrams showing input and output waveforms and an optical spectrum of the saturation amplifier,

FIG.30 is a block diagram showing an optical transmitter in a thirteenth preferred embodiment according to the invention,

FIG.31 is a diagram showing an input-output characteristic of a circuit composed of a diode and a amplifier in FIG.30,

FIG.32 is a block diagram showing an optical transmitter in a fourteenth preferred embodiment according to the invention, and

FIG.33 is a block diagram showing an optical transmitter in a fifteenth preferred embodiment according to the invention.

A method for generating a duobinary signal and an optical transmitter using the same method in the first preferred embodiment will be explained in FIG.8. The first embodiment is adapted to an optical transmitter in an 10 Gb/s optical duobinary modulation-direct detection reception manner. As shown in FIG.8, the output of a 1.5 μm band semiconductor laser 1 is input to a Mach-Zehnder(MZ) optical intensity modulator 2 which is composed of an lithium niobate($LiNbO_3$, hereinafter referred to as 'LN') optical waveguide, and then its output is input to a LN optical phase modulator 3. The LN optical intensity modulator 2 turns ON or OFF the optical output according to the value, 1 or 0, of an electrical signal to be input. Also, the LN optical phase modulator 3 modulates the optical phase into π or 0 according to the value, 1 or 0, of an electrical signal to be input. A 10 Gb/s data signal 6 is divided into two signals, one of which is input to the LN optical intensity modulator 2 to intensity-modulate signal light, and the other of which is input to a precoder 7 and is encoded based on the relation that the output is inverted when the input is 0, as described earlier. An example of a circuit composition of the precoder 7 and an input-output logic table are shown in FIG.9. FIGS.10A to 10D illustrate the operation of the precoder 7 and the relation between the amplitude and phase of the modulated signal light 4. The encoded data signal 8 is input to a 0.5-bit delay circuit 9 and delayed therein, thereafter input to the LN optical phase modulator 3 to intensity-modulate the signal light. Meanwhile, the 0.5-bit delay circuit 9 is so adjusted that, considering the propagation delay time from the LN optical intensity modulator 2 to the LN optical phase modulator 3, the 0.5-bit delay phase relation between the intensity modulation and the phase modulation is obtained.

As the result of the optical modulation by the above composition and process, the measured full width at half maximum of the optical spectrum of the signal light 4 output is 5 GHz. When signal light by standard intensity modulation is output stopping the phase modulation in the same composition, the full width at half maximum of the optical spectrum is about 10 GHz. Thus, it is proved

that the bandwidth is reduced to 1/2 due to the invention. When the signal light 4 is transmitted through a 1.3 μm zero-dispersion optical fiber with a length of 150 km, the dispersion deterioration after the transmission is less than 1 dB. The standard intensity-modulated signal light cannot be received at 50 km due to the waveform deterioration. Namely, it is proved that the signal light 4 produced according to the invention is durable against the dispersion.

A method for generating a duobinary signal and an optical transmitter using the same method in the second preferred embodiment will be explained in FIG.11. The second embodiment is given as an example using an integrated light source 11 where an optical intensity modulator and an optical phase modulator are fabricated using semiconductor and are integrated with a distributed feedback(DFB) semiconductor laser. The optical intensity modulator used is an electric-field-absorption-type(EA) optical intensity modulator. The optical phase modulator used is a modulator of the type that the phase modulation is conducted by using the effect that a refractive index in semiconductor is varied by the application of electric field.

As the result of the modulation experiment at 10 Gb/s using the integrated light source 11, it is proved that the spectrum width and the dispersion deterioration characteristic which are similar to those in the first embodiment are obtained. Also, the integration of the light source and the optical modulator enables the miniaturization of the optical transmitter.

A method for generating a duobinary signal and an optical transmitter using the same method in the third preferred embodiment will be explained in FIG.12. The third embodiment is given as an example using a DFB/EA integrated light source 15 where an optical intensity modulator and a DFB semiconductor laser are integrated. Instead of the phase modulation, used is the direct modulation phase shift keying(PSK) technique where the optical phase modulation is conducted by pulsatively modulating the injection current of the DFB semiconductor laser and optical-frequency modulating. A direct modulation PSK encoder 16 generates pulses with a width shorter than 1 time slot at the rising and falling of data series to be phase-modulated, thereby optical-frequency-modulating the signal light. By adjusting the degree of frequency modulation, the modulation equivalent to the 0-π phase modulation is conducted.

As the result of the modulation experiment at 10 Gb/s using the integrated light source 15, it is proved that the spectrum width and the dispersion deterioration characteristic which are similar to those in the first and second embodiments are obtained. Also, the integration of the light source and the optical modulator enables the miniaturization of the optical transmitter.

A method for generating a duobinary signal and an optical transmitter using the same method in the fourth preferred embodiment will be explained in FIG.13. The fourth embodiment is given as an example where a data signal 6 to be input to an optical intensity modulator 2 is waveform-transformed by a waveform equalizer 18. Examples of an input waveform and an output waveform of the waveform equalizer 18 are shown in FIG.14. As shown in FIG.14, the cross point of data signal is moved close to a level of 1 and a level of zero is pointed properly. By the transformation of waveform, the variation of phase and amplitude at the level of zero becomes closer to that of the ideal optical duobinary signal light, and the durability against the dispersion can be enhanced.

As the result of the transmission at 10 Gb/s using the waveform equalizer 18, it is proved that, when the signal light 4 is transmitted through a 1.3 μm zero-dispersion optical fiber with a length of 200 km, the dispersion deterioration after the transmission is less than 1 dB. In contrast with this, when the waveform equalizer 18 is not used, there occurs a deterioration of 1 dB for about 150 km transmission.

A method for generating a duobinary signal and an optical transmitter using the same method in the fifth preferred embodiment will be explained in FIG.15. The fifth embodiment is given as an example where an optical intensity modulator and an optical phase modulator are given by a push-pull type MZ modulator 19 which is integrated on a LN substrate. By modulating each of arms of the push-pull optical modulator 19 with V_π, it operates as an optical phase modulator, and, by modulating each of arms of the push-pull optical modulator 19 with $V_\pi/2$, it operates as an optical intensity modulator. Also, it can operate as an ideal modulator that higher harmonic components are suppressed since unnecessary chirp does not occur.

As the result of the modulation experiment at 10 Gb/s by the above composition, it is proved that, as compared with the first to fourth embodiments, components near the base of the optical spectrum are best suppressed and higher harmonic components are suppressed.

A method for generating a duobinary signal and an optical transmitter using the same method in the sixth preferred embodiment will be explained in FIG.16. The sixth embodiment is given as an example using a module 28 where the integrated light source 11 composed of the optical intensity modulator, optical phase modulator and DFB semiconductor laser in the second embodiment in FIG.11 is airtightly sealed. In the integrated light source 11a, the positions of the optical intensity modulator and the optical phase modulator are reverse to those of the integrated light source 11. Also, a D-type flip-flop 25, where an output Q and an inverted output Q(¯, bar) are obtained, is used to divide the data signal 6. Thereby, the effect of waveform adjustment as well as the dividing can be obtained. Meanwhile, an EX-OR circuit 26 is used since the precoder inputs the inverted output Q(bar). Also, to easily adjust the phase relation of modulated signals, at an intensity modulation terminal 29 and a phase modulation terminal 30 of the integrated light source module 28, delay time is adjusted by a

microstrip delay line 31 so that the difference between the propagation delay and the wiring delay of light in the integrated light source 11a is zero between the intensity-modulated signal and phase-modulated signal.

As the result of the modulation experiment at 20 Gb/s by the above composition, the operation is well conducted. Also, the high-speed operation can be performed by shortening the wiring and using the small module.

A method for generating a duobinary signal and an optical transmitter using the same method in the seventh preferred embodiment will be explained in FIG.17. The seventh embodiment is given as an example where the precoder is composed of a counter 35. Q(bar) output of a D-type flip-flop 25 is input to an ENABLE terminal of the binary counter 35. Namely, when the data signal 6 is 0, Q(bar) becomes 1 and then the counter 35 counts a clock signal 24. As a result, output Q_0, which represents the first place of the counter 35, shifts alternately between 1 and 0. Thus, it can conduct the same operation as the precoder 7 in FIG.9.

As the result of the modulation experiment at 10 Gb/s by the above composition, it is proved that it operates like the case using the precoder composed of EX-NOR.

A method for generating a duobinary signal and an optical transmitter using the same method in the eighth preferred embodiment will be explained in FIG.18. The eighth embodiment is given as an example where two optical intensity modulators are parallel disposed, whereby two divided lights are switched individually, thereafter coupled to give signal light 4 with a phase difference of π. First, the output of a semiconductor laser 1 is input to a parallel-type optical modulator 36. Then, the light input is divided into the two lights in the parallel-type optical modulator 36, then input to the first and second optical intensity modulators 38a and 38b, respectively. One of the outputs of the first and second optical intensity modulators 38a, 38b is phase-shifted by a π optical phase shifter 37 to give the phase difference of π between the two output lights, thereafter coupled. The entire parallel-type optical modulator 36 is formed as a MZ interferometer. The data signal 6 is passed through the precoder 7 like that shown in FIG.9, then input to a parallel-type precoder 39, therein converted into first and second encoded data signals 40a, 40b, which are input to the first and second optical intensity modulators 38a and 38b, respectively. The input-output relations in the parallel-type precoder 39 are shown in FIG.19. The first and second encoded data signals 40a, 40b are, as shown in FIG.18, represented by Q_0 and Q_π, respectively. From the current data signal D(i) and data signal 1-bit before D(i-1), the analog addition, (D(i)+D(i-1)), gives three values of 0, 1 and 2. The three values are mapped to three states, (1, π), (0, unfixed) and (1,0), where the amplitude and phase of light are represented by (A, Φ). This is conducted by using the combination of Q_0 and Q_π in FIG.19. Meanwhile, when both Q_0 and Q_π are 1 and lights on both the arms are ON, the phase difference between the lights is π. Therefore, the power of the output light becomes zero when interfered at the coupling position. The input and output of the parallel-type precoder 39 as shown in FIG.19 are given by:

$$Q_0=D(i), \quad Q_\pi=\overline{D(i-1)}$$

Circuit examples of the parallel-type precoder 39 are shown in FIGS. 20 and 21.

As the result of the modulation experiment at 10 Gb/s by the above composition, it is proved that a spectrum width and a dispersion deterioration characteristic equivalent to those in the signal light obtained by the cascade modulation in the first to seventh embodiments are obtained.

A method for generating a duobinary signal and an optical transmitter using the same method in the ninth preferred embodiment will be explained in FIG.22. The ninth embodiment is given as an example using a parallel-type push-pull optical modulator 41 where push-pull MZ interferometers are disposed on both the arms of a MZ interferometer. A bias electrode 43 is disposed on the optical waveguide of one of the arms, where the optical phase is shifted by π by applying a voltage. Though, in FIG.22, a bias-voltage applying circuit for the push-pull MZ interferometers disposed on both the arms is not shown, the bias voltage is so adjusted that the intensity modulation is optimumly conducted by both the MZ interferometers. The outputs Q, Q(bar) of a D-type flip-flop 25 are individually divided into two signals. The push-pull MZ modulator for phase-zero signal light is driven Q and Q(bar), and the push-pull MZ modulator for phase-π signal light is driven by 1-bit delayed Q and Q(bar). As a result, it can operate like the logic of the parallel-type precoder 39 as shown in FIG.19.

As the result of the modulation experiment at 10 Gb/s by the above composition, it is proved that it operates stably like the eighth embodiment.

Though the invention is explained by above embodiments, the invention is not limited to their compositions and can receive various modifications.

Also, the invention can be applied to any wavelength, while the above embodiments employ the 1.5 μm wavelength-band semiconductor laser. Furthermore, any laser, such as a gas laser, a solid-state laser and an organic laser, other than the semiconductor laser is applicable. The carrier wave can be any electromagnetic wave, such as microwave and millimetric wave, other than light.

Though the above experiments are conducted at the bit rates of 10 and 20 Gb/s, the bit rate may be higher or lower than these.

Also, any material of the optical intensity modulator can be used, while the optical intensity modulators in

the embodiments use LN and semiconductor. Furthermore, other than the MZ-type and electric field absorption(EA) type modulators, any optical intensity modulators, such as acousto-optic effect type, electro-optic effect type, polarization-rotation type and non-linear effect type, which can modulate an optical intensity according to an input signal, may be used. Also, the input signal is not limited to an electrical signal, e.g., an optical intensity modulator controlled by light may be used. Also in the optical phase modulator, the material, composition, effect to be employed etc. are not limited, i.e., any type of optical phase modulators, which can modulate an optical phase according to an input signal, may be used.

Though the circuit examples of the precoder are shown in the above embodiments, any logic circuit, such as AND, OR and flip-flop, including an analog circuit, may be used.

Also, the phase inversion may be omitted when an amplitude of zero occur continuously, while the phase is always inverted when the amplitude of light is zero in the embodiments.

Though the 0.5-bit delay circuit 9 serves to delay by 0.5 bit the timing of intensity modulation and phase modulation, this delay value is not limited. Namely, when there exists a propagation delay in the connection cable, the delay value needs to be adjusted shifting from 0.5 bit. The position of the 0.5-bit delay circuit 9, which is located after the precoder in the embodiments, may be located before the precoder. Alternatively, an optical delayer may be used to delay by 0.5 bit in the optical region. The delay may be adjusted wherever the timing of intensity modulation and phase modulation can be shifted by 0.5 bit. The 1-bit delay circuit 27 can be modified as well.

Though the π optical phase shifter 37 serves to shift by π the phase difference between the two divided signal lights, this shift value is not severely limited when there exists an optical-path-length difference or birefringence on both the arms of the MZ interferometer. The π phase shift may be achieved by using the optical-path-length difference or birefringence in the optical waveguide, refractive-index variation of the modulator material by applying a current or electric field, non-linear effect etc. Also, the position of the π optical phase shifter 37 may be before the optical intensity modulator 38a or 38b, and the optical dividing or coupling part may have this function. Also, a phase difference of $-\pi$ may be used.

A method for generating a duobinary signal and an optical transmitter using the same method in the tenth preferred embodiment will be explained in FIG.23. The tenth embodiment is given as an example where, in the duobinary optical transmitter of the first embodiment in FIG.8, the bias of the MZ modulator is adjusted to obtain an ideal duobinary waveform. An optical intensity modulator 2 is provided with a bias circuit 66 which sets a modulation operating point. The bias is, as shown in FIG.6B, set to be shifted to the side of the transmission peak from the center of the modulation characteristic 61 of the modulator. The amount of shifting is preferably about 10 to 20 % of V_π. Thereby, the cross point of the optical waveform after the intensity modulation is shifted to the side of optical transmission to be close to the ideal duobinary signal waveform. The measurement results for spectrum and optical waveform of 10 Gbps duobinary modulation light generated by the above composition are shown in FIGS.24A and 24B, respectively. On the other hand, the measurement results for spectrum and optical waveform in the case that the average of a voltage signal to be applied to the LN optical intensity modulator is conventionally set to be the center of the extinction curve are shown in FIGS.25A and 25B, respectively. Comparing FIG.24B with FIG.25B, it is proved that, in this embodiment, the high-frequency components higher than 5 GHz is suppressed.

A method for generating a duobinary signal and an optical transmitter using the same method in the eleventh preferred embodiment will be explained in FIG.26. The eleventh embodiment is given as an example where, to the duobinary optical modulator in FIG.23, an optical spectrum analyzer 67 for detecting the spectrum width of light output from the modulator, a computer 68 for processing the data from the optical spectrum analyzer 67 to calculate the spectrum width of modulated light, and a control circuit 69 for controlling a voltage applied to a bias circuit 66 to minimize the spectrum width. In this composition, the bias to the optical intensity modulator 2 is controlled to minimize the spectrum width measured by the optical spectrum analyzer 67. Therefore, even when the modulation characteristic of the optical intensity modulator 2 is varied, the spectrum width is always kept to be minimum and the stable operation is thereby obtained.

A method for generating a duobinary signal and an optical transmitter using the same method in the twelfth preferred embodiment will be explained in FIG.27. The eleventh embodiment is given as an example where the modulation optical waveform is brought close to an ideal duobinary waveform by using a non-linear input-output characteristic of a saturation amplifier 70. The saturation amplifier 70 has the input-output characteristic 71 as shown in FIG.28. When a binary signal as shown in FIG. 29A is input to this circuit, the cross point of the output signal is biased upward as shown in FIG.29B, whereby the output signal close to the ideal duobinary modulation waveform is obtained. When the optical duobinary signal is generated by driving the optical intensity modulator 2 through this electrical signal, the operating point is so set that light is transmitted through when the input voltage is high and light is intercepted when the input voltage is low. By this setting, the cross point of the optical waveform after modulation is biased to the side of optical transmission and the high-frequency components of optical spectrum is reduced as shown in FIG. 29C.

Meanwhile, an electric circuit having a non-linear input-output characteristic is not limited to the saturation

amplifier. For example, a combination of a diode and an amplifier can be used.

A method for generating a duobinary signal and an optical transmitter using the same method in the thirteenth preferred embodiment, which employs such a combination, will be explained in FIGS.30. The input-output characteristic 74 of a circuit where a diode 72 and an amplifier 73 are connected in series is shown in FIG. 31. Contrary to the case using the saturation amplifier, the gain is lowered where the input voltage is low. Therefore, the cross point of the output waveform is biased downward. Using this waveform, the optical intensity modulator 2 is so operated that light is intercepted when the input voltage is high and light is transmitted through when the input voltage is low. By this setting, the cross point of the optical waveform after modulation is biased to the side of optical transmission and the high-frequency components of optical spectrum is reduced.

Though, in the twelfth and thirteenth embodiments, the operation state of the optical intensity modulator is defined according to the modulation characteristic curve, it will be easily appreciated that even the reverse operation state of the optical intensity modulator is applicable by inverting the modulated waveform by inserting an inverting amplifier after the non-linear circuit.

A method for generating a duobinary signal and an optical transmitter using the same method in the fourteenth preferred embodiment will be explained in FIG. 32. The fourteenth embodiment is given as an example where means for detecting an optical spectrum width is provided for the output of the optical intensity modulator in the twelfth embodiment to control the bias of an input signal to the non-linear electric circuit to minimize the spectrum width. The spectrum width detecting means is composed of an optical spectrum analyzer 67, a data processing computer 68 and a control circuit 69, like the eleventh embodiment. The control circuit 69 controls the bias applied to the input signal to the non-linear circuit to minimize the spectrum width to be calculated by the computer 68. Thereby, even when the input-output characteristic of the electric circuit is varied, the modulated waveform is always kept to have a narrow spectrum width.

A method for generating a duobinary signal and an optical transmitter using the same method in the fifteenth preferred embodiment will be explained in FIG. 33. The fifteenth embodiment is given as an example where the components of the first embodiment are used as they are and the LN optical intensity modulator 2 and the LN optical phase modulator 3 are so connected that their optical axes are inclined by 45° to each other. By inputting light while inclining by 45° the main axis of the polarization of signal light 4 to the optical axis of the optical phase modulator 3, only the component in the direction of the optical axis of the signal light 4 is phase-modulated and the component in the direction orthogonal to the optical axis of the signal light 4 is not phase-modulated. As a result, the polarization state of the signal light is polarization-modulated according to a driving signal to the optical phase modulator 3. The signal light is the sum of the phase-modulated duobinary signal and the non-phase-modulated intensity modulation signal light. Though it is not a perfect duobinary signal, the optical spectrum is a little narrowed since the component of the intensity modulation light is halved. Furthermore, since the signal light is polarization-modulated, a variation in amplification factor(polarization hole burning) depending upon polarization to be supplied etc., which is a problem of a system using an optical amplifier, can be suppressed.

As the result of the optical modulation by the above composition and process, the measured full width at half maximum of the optical spectrum of the signal light 4 output is 7.5 GHz. When signal light by standard intensity modulation is output stopping the phase modulation in the same composition, the full width at half maximum of the optical spectrum is about 10 GHz. Thus, it is proved that the bandwidth is reduced due to the invention. When the signal light 4 is input and transmitted through an optical amplification repeating system with a total length of 1000 km which is composed of optical amplification repeaters disposed at intervals of 50 km optical fiber, it is proved that the polarization hole burning of the optical amplification repeater is suppressed due to the polarization modulation and that the optical signal-to-noise ratio(optical SNR) is improved by 3dB compared with a case without the polarization modulation.

Though, in the fifteenth embodiment, the optical phase modulator 3 whose optical axis direction is inclined by 45° is used, an optical polarization modulator is not limited to this. For example, it may be composed by dividing the signal light into two polarized waves that are orthogonal to each other, then phase-modulating only one of the signal light through the optical phase modulator, again coupling them. Also, it is not limited to the LN phase modulator. The material may be of semiconductor, organic, inorganic, an optical fiber etc. if it is usable for the high-speed polarization modulation. The modulation manner may be electrical, magnetical, mechanical, optical etc.

Although the invention has been described with respect to specific embodiment for complete and clear disclosure, the appended claim are not to be thus limited but are to be construed as embodying all modification and alternative constructions that may be occurred to one skilled in the art which fairly fall within the basic teaching here is set forth.

Each feature disclosed in this specification (which term includes the claims) and/or shown in the drawings may be incorporated in the invention independently of other disclosed and/or illustrated features.

The text of the abstract filed herewith is repeated here as part of the specification.

Disclosed is a method for generating a duobinary signal which has the step of: modulating individually an

intensity and a phase of carrier wave. Also disclosed is a duobinary-manner optical transmitter which has: a laser device which outputs signal light; an optical intensity modulator which intensity-modulates the signal light according to a first data signal generated by dividing a data signal into two signals; a precoder which inputs a second data signal generated by dividing the date signal into two signals; and an optical phase modulator which phase-modulates the intensity-modulated signal light according to a signal which is obtained delaying 0.5 bit an output signal of the precoder.

Claims

1. A method of generating a duobinary signal, comprising the step of modulating individually an intensity and a phase of a carrier wave.

2. A method for generating a duobinary signal, according to Claim 1, wherein the phase modulation of the carrier signal is π when said intensity is zero.

3. A duobinary-type optical transmitter, comprising means for modulating individually an intensity and a phase of a carrier wave.

4. A duobinary-type optical transmitter, comprising:

   a laser device for outputting a light signal;
   an optical intensity modulator for intensity-modulating said signal according to one of two data signals generated by dividing a data signal into two signals;
   a precoder for receiving the other of the two data signals; and
   an optical phase modulator for phase-modulating said intensity-modulated signal according to a signal obtained by delaying by 0.5 bit an output signal of said precoder.

5. A transmitter according to Claim 4, wherein at least two of said laser device, said optical intensity modulator and said optical phase modulator are integrated.

6. A transmitter according to Claim 4, adapted to input said data signal to said optical intensity modulator after its waveform has been varied by a waveform equalizer.

7. A transmitter according to Claim 4, wherein at least one of said optical intensity modulator and said optical phase modulator is a push-pull type optical modulator.

8. A transmitter according to Claim 4, wherein said optical intensity modulator and said optical phase modulator are reversely cascade-connected.

9. A duobinary-type optical transmitter, comprising:

   a precoder for receiving one of two data signals generated by dividing a data signal into two signals;
   a direct modulation phase shift keying encoder for delaying an output of said precoder by 0.5 bits;
   a laser device for outputting signal light phase-modulated by modulating an injected current according to an output of said direct modulation phase shift keying encoder; and
   an optical intensity modulator for intensity-modulated for intensity-modulating said phase-modulated signal light according to the other of said two data signals.

10. A transmitter according to Claim 9, wherein said direct modulation phase shift keying encoder is adapted to output a pulse with a pulse width shorter than one time slot when the precoder inverts said first data signal from 0 to 1 or from 1 to 0.

11. A method of generating a duobinary signal, comprising the steps of:

   providing two carrier waves with an equal frequency;
   intensity-modulating individually said two carrier waves; and
   coupling said two intensity-modulated carrier waves so that the phase difference of said intensity-modulated carrier waves is π.

12. A duobinary-type optical transmitter comprising

   means for providing two carrier waves with an equal frequency;
   means for intensity-modulating individually said two carrier waves; and
   means for coupling said two intensity-modulated carrier waves so that the phase difference of said intensity-modulated carrier waves is π.

13. A duobinary-type optical transmitter comprising:

   a laser device for outputting a light signal;
   an optical divider for dividing said signal into first and second light signals;
   a first optical intensity modulator for receiving said first light signal;
   a second optical intensity modulator for receiving said second light signal;
   an optical coupler for coupling lights output from said first and second optical intensity modulator after phase-shifting at least one of said

output lights so as to give a phase difference of π between said output signals of said first and second optical intensity modulators; and
a precoder for receiving a data signal;
wherein said first optical intensity modulator is driven by a first encoded signal generated by dividing an encoded signal output from said precoder into two signals, and said second optical intensity modulator is driven by a signal which is obtained by delaying by 1 bit a second encoded signal generated by dividing said encoded signal into said two signals, and inverting the value of the second encoded signal.

14. A transmitter according to Claim 11, wherein at least one of said first and second optical intensity modulators is a push-pull type optical modulator.

15. A transmitter according to Claim 4, wherein a waveform of said light signal is variable by changing an operating point of said optical intensity modulator.

16. A transmitter according to Claim 15, further comprising:

means for measuring an optical spectrum of light;
means for calculating a spectrum width from measurement data output from said optical spectrum measuring means; and
means for controlling said operating point of said optical intensity modulator;
wherein said operating point of said optical intensity modulator is controllable by said controlling means to minimize said spectrum width.

17. A transmitter according to Claim 4, wherein a waveform of said first data signal is variable through a non-linear electric circuit.

18. A transmitter according to Claim 17, further comprising:

means for measuring an optical spectrum of light;
means for calculating a spectrum width from measurement data output from said optical spectrum measuring means; and
means for controlling a bias of said first data signal to be input to said non-linear electric circuit;
wherein said bias is controllable by said bias controlling means to minimize said spectrum width.

19. A method of generating a duobinary signal, comprising the step of modulating individually an intensity and a polarization of a carrier wave.

20. A method according to Claim 19, wherein said polarization modulation is varied when said intensity is zero.

21. A duobinary-type optical transmitter comprising means for modulating individually an intensity and a polarization of a carrier wave.

22. A duobinary-type optical transmitter, comprising:

a laser device for outputting a light signal;
an optical intensity modulator for intensity-modulating said signal light according to one of two data signals generated by dividing a data signal into two signals;
a precoder for receiving the other of said two data signals; and
an optical polarization modulator for polarization-modulating said intensity-modulated light signal according to a signal obtained by delaying by 0.5 bit an output signal of said precoder.

23. A transmitter according to Claim 22, wherein said polarization modulator comprises an optical phase modulator, and when polarization modulation is conducted by supplying a main axis direction of polarization of said intensity-modulated light signal at 45° to an optical axis of said optical phase modulator.

24. A transmitter according to any of Claims 4 to 10, 13 to 18, 22 and 23, wherein said precoder is adapted to invert the second data signal from 0 to 1 or from 1 to 0 when the value of said second data signal is 0 and not to invert the second data signal when the value of said second data signal is 1.

FIG. 1 PRIOR ART

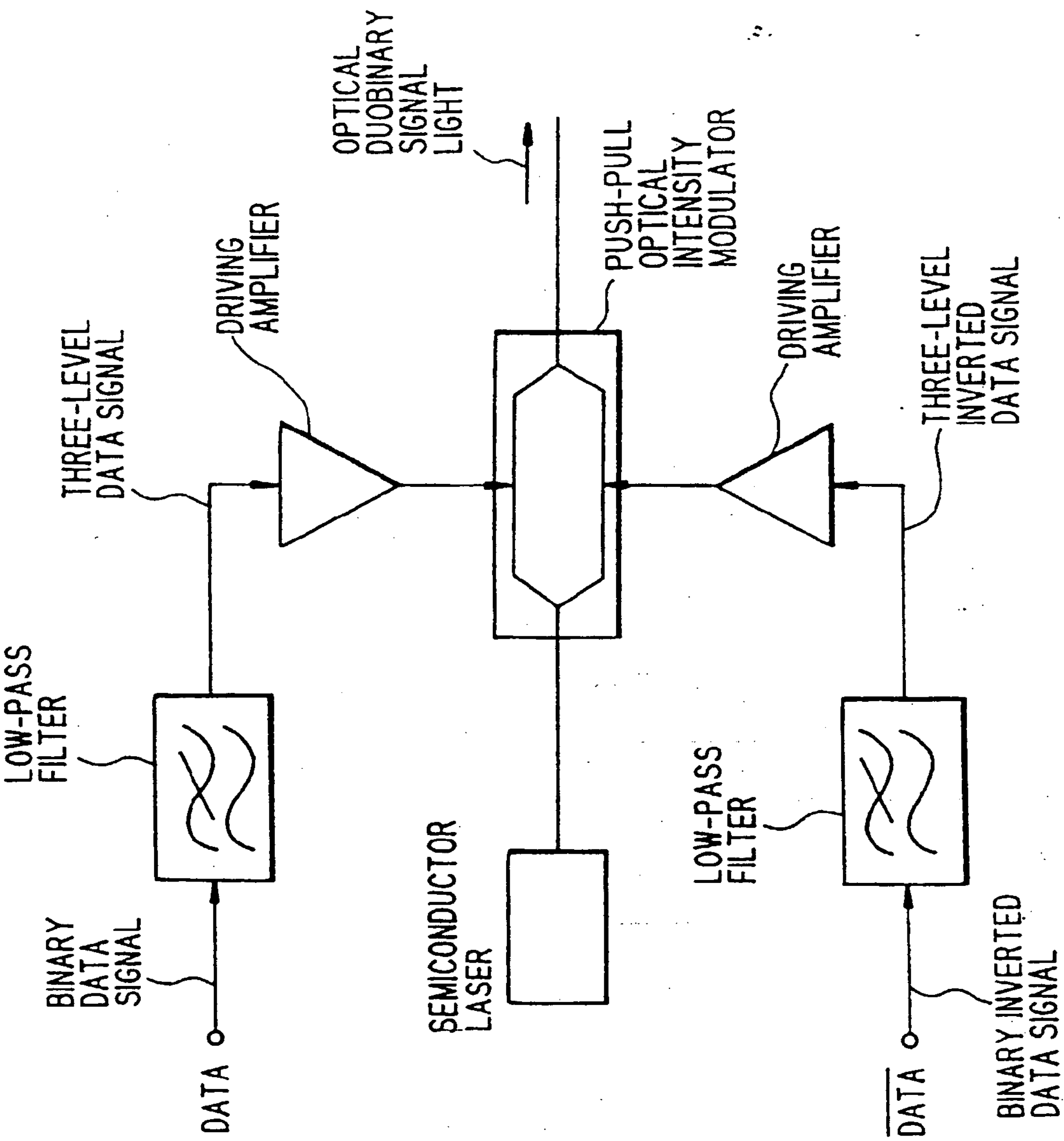


FIG.2 PRIOR ART

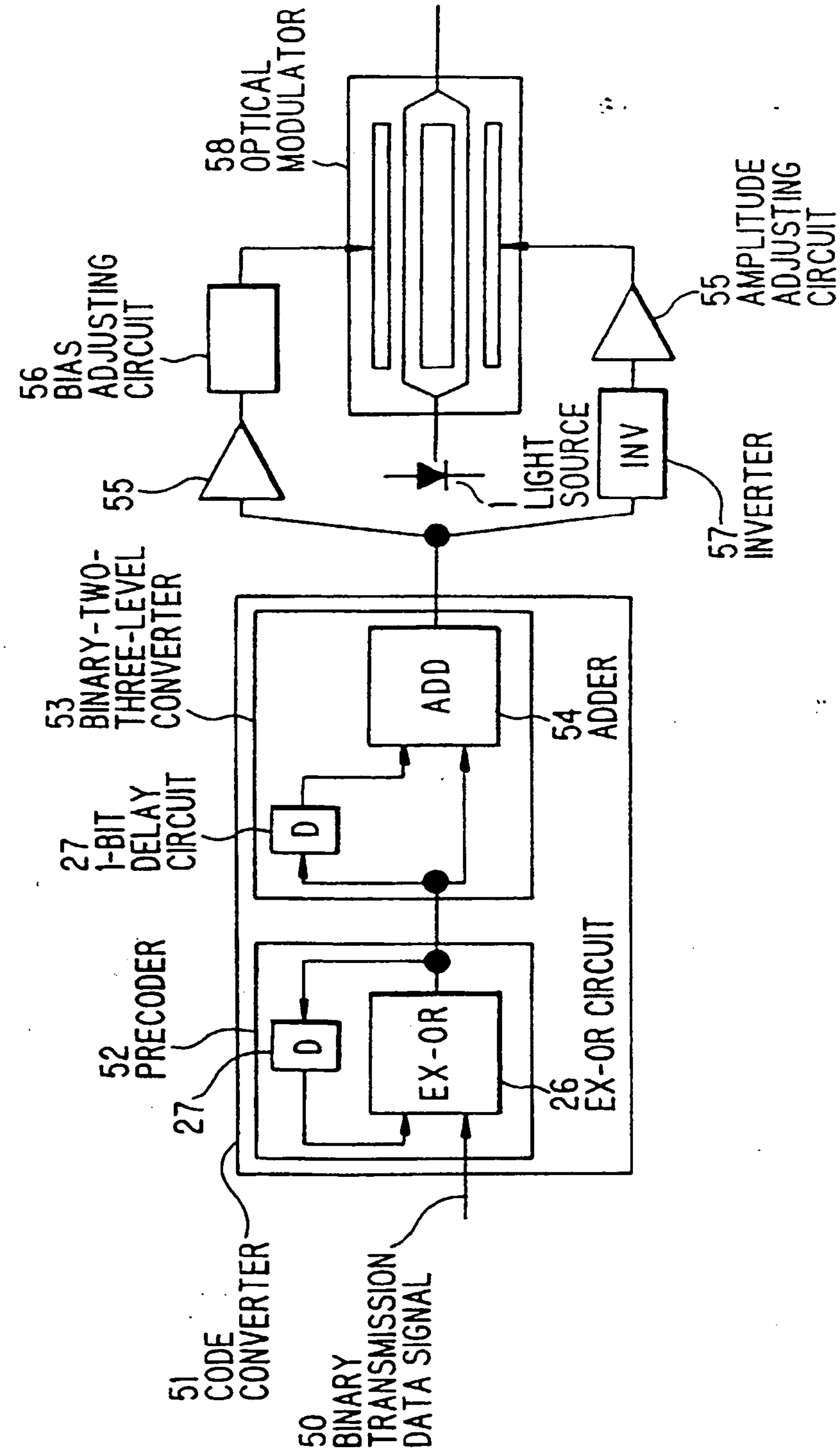


FIG. 3 PRIOR ART

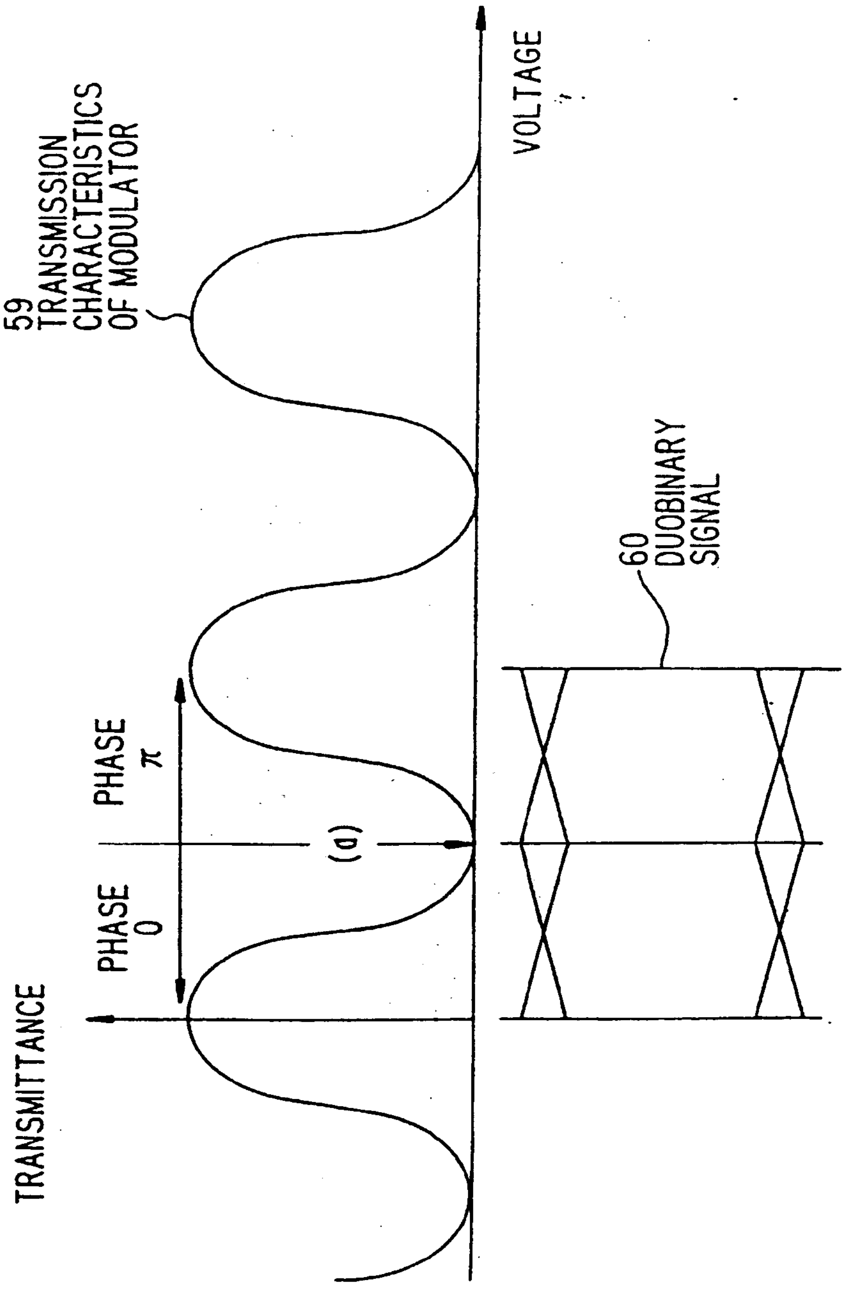


FIG.4 PRIOR ART

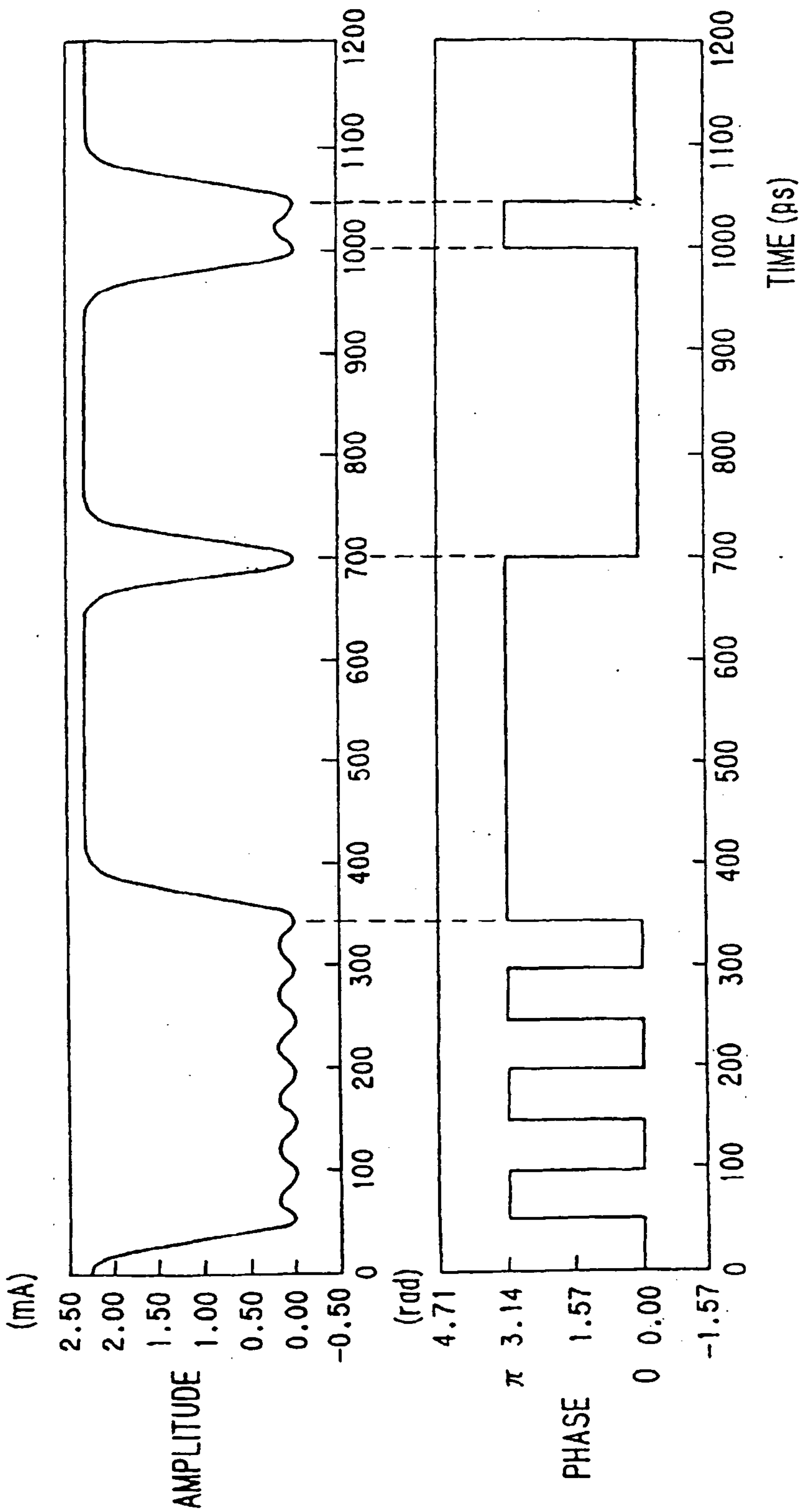


FIG.5A

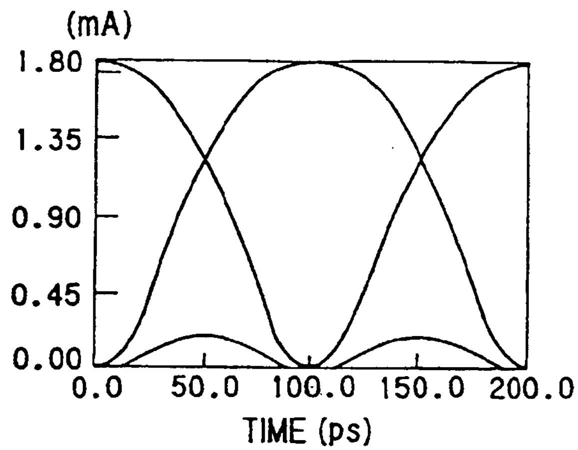

(mA)
1.80
1.35
0.90
0.45
0.00
0.0
50.0
100.0
150.0
200.0
TIME (ps)

FIG.5B

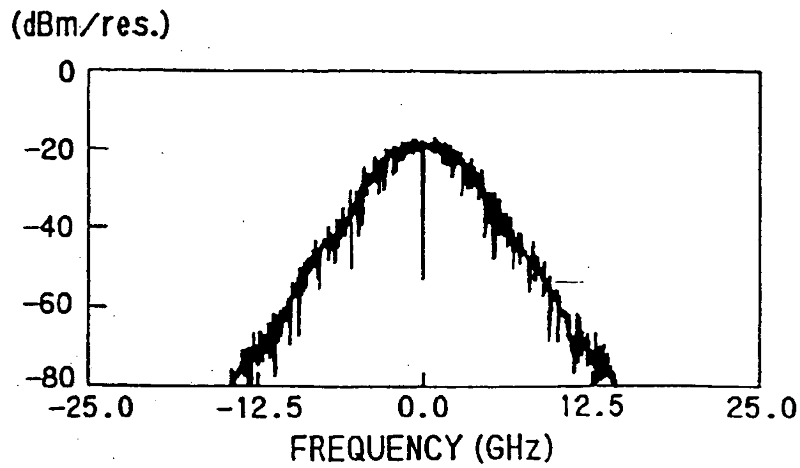

(dBm/res.)
0
-20
-40
-60
-80
-25.0
-12.5
0.0
12.5
25.0
FREQUENCY (GHz)

FIG.6A

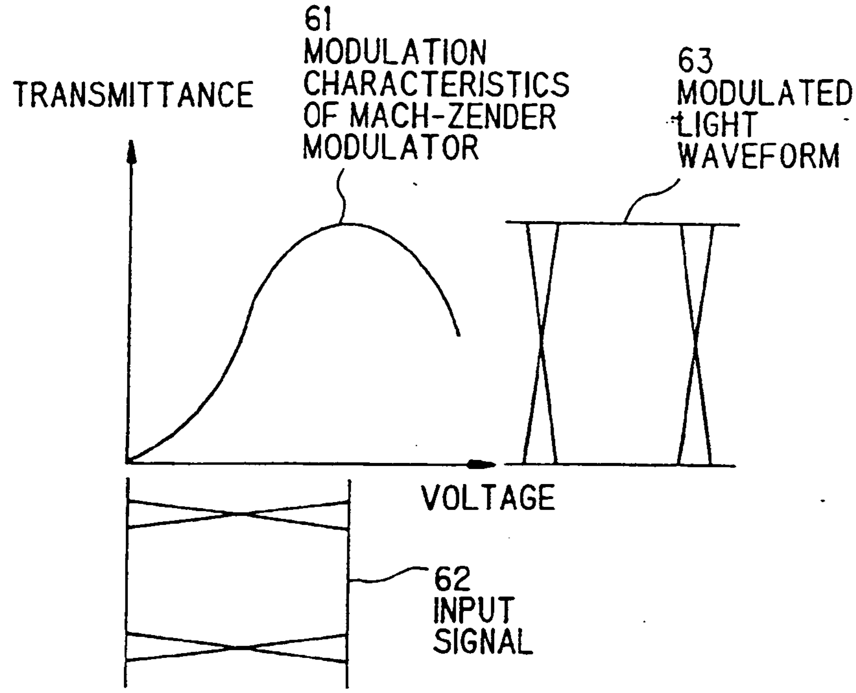

61
MODULATION
CHARACTERISTICS
OF MACH-ZENDER
MODULATOR
TRANSMITTANCE
63
MODULATED
LIGHT
WAVEFORM
VOLTAGE
62
INPUT
SIGNAL

FIG.6B

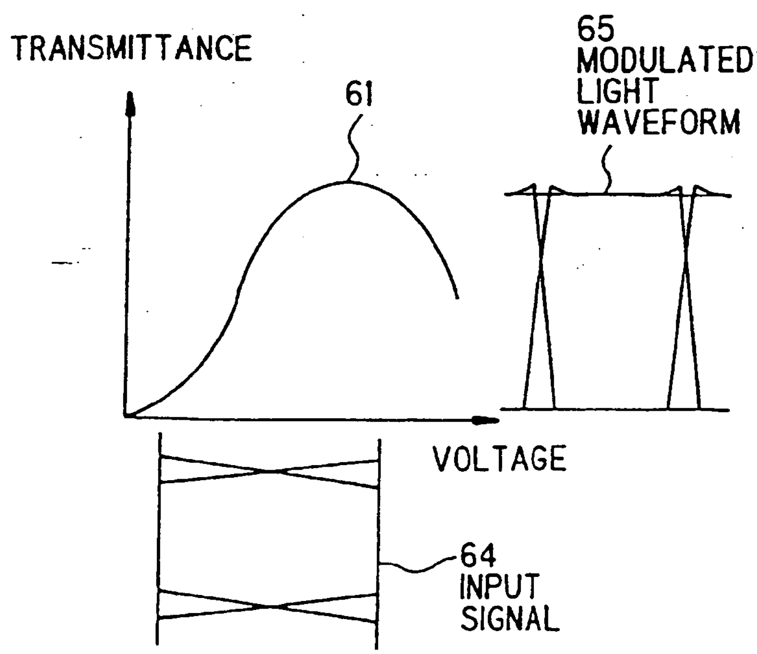

TRANSMITTANCE
61
65
MODULATED
LIGHT
WAVEFORM
VOLTAGE
64
INPUT
SIGNAL

FIG. 7A

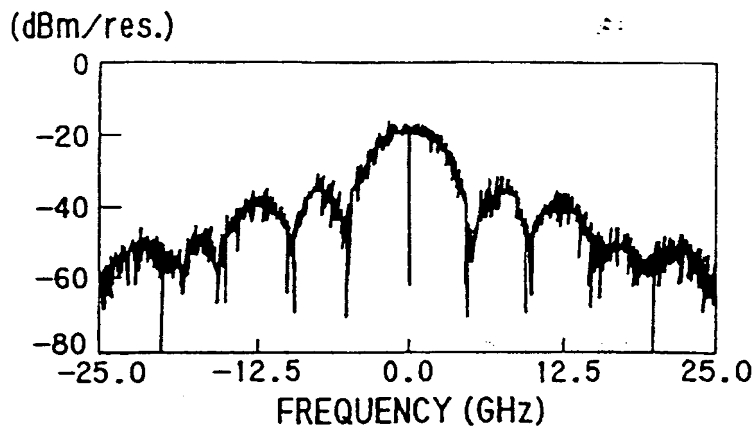

(dBm/res.)
0
-20
-40
-60
-80
-25.0
-12.5
0.0
12.5
25.0
FREQUENCY (GHz)

FIG. 7B

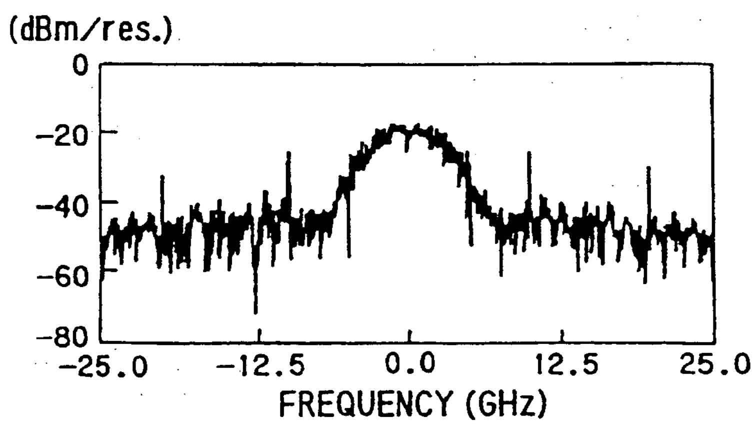

(dBm/res.)
0
-20
-40
-60
-80
-25.0
-12.5
0.0
12.5
25.0
FREQUENCY (GHz)

FIG.8

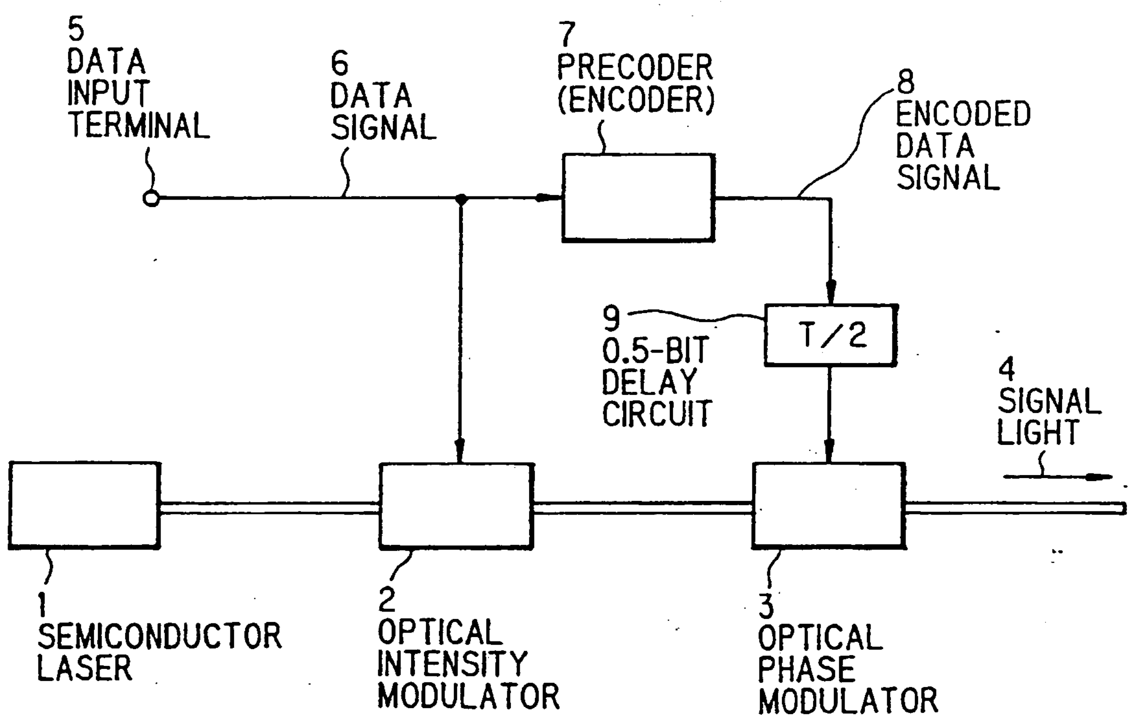
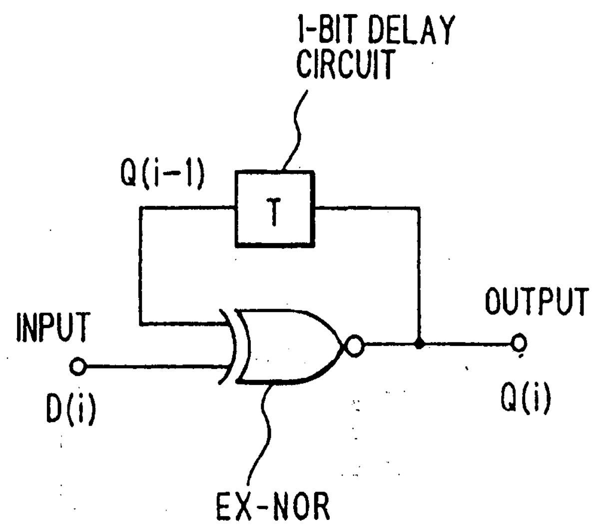

5
DATA
INPUT
TERMINAL
6
DATA
SIGNAL
7
PRECODER
(ENCODER)
8
ENCODED
DATA
SIGNAL
9
0.5-BIT
DELAY
CIRCUIT
T/2
4
SIGNAL
LIGHT
1
SEMICONDUCTOR
LASER
2
OPTICAL
INTENSITY
MODULATOR
3
OPTICAL
PHASE
MODULATOR

FIG.9



INPUT DATA SIGNAL D(i)	OUTPUT SIGNAL 1-BIT BEFORE Q(i−1)	OUTPUT SIGNAL Q(1)
0	0 →	1
	1 →	0
1	0 →	0
	1 →	1

FIG. 10A

FIG. 10B

FIG. 10C

FIG. 10D

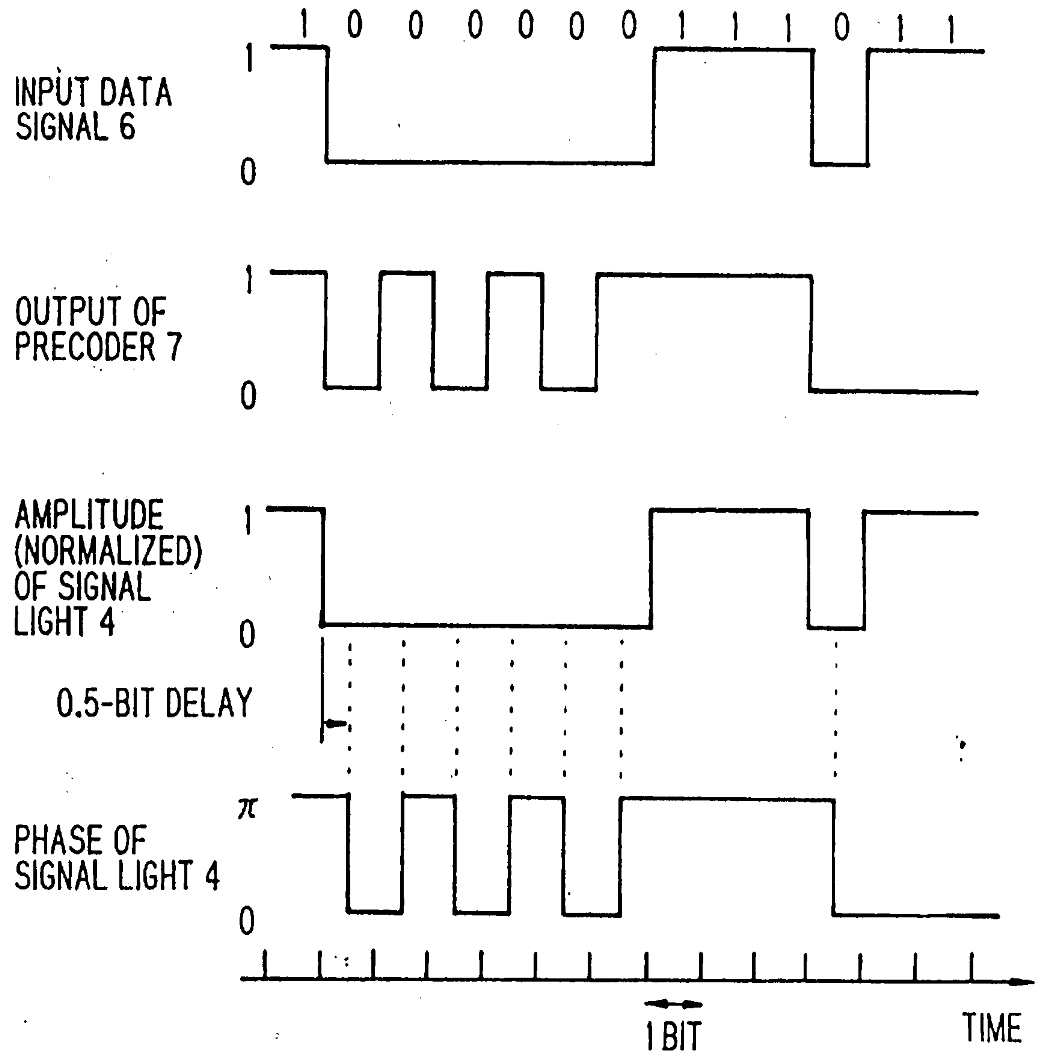


FIG. 11

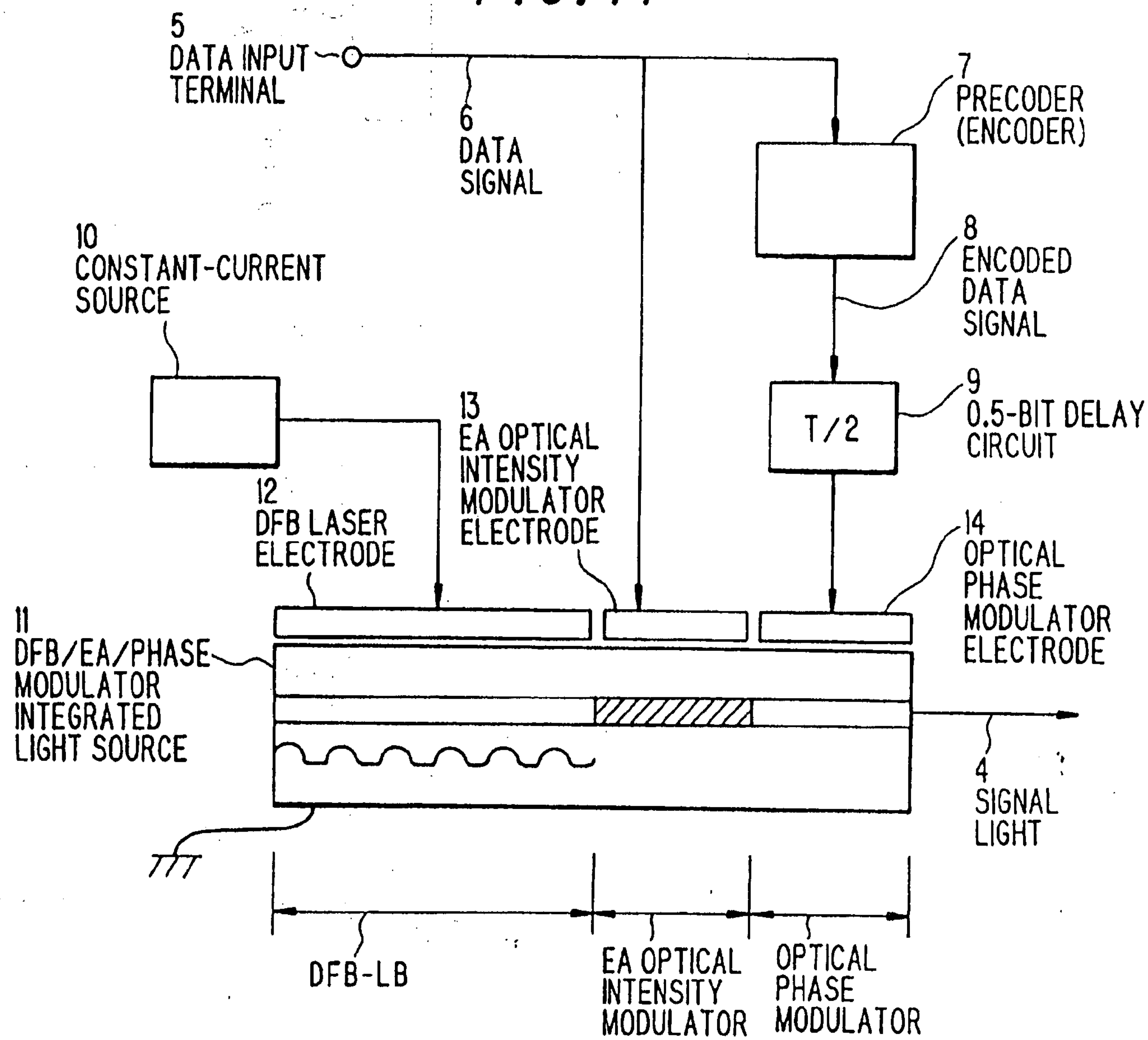

5
DATA INPUT TERMINAL
6
DATA SIGNAL
7
PRECODER (ENCODER)
8
ENCODED DATA SIGNAL
9
0.5-BIT DELAY CIRCUIT
T/2
10
CONSTANT-CURRENT SOURCE
12
DFB LASER ELECTRODE
13
EA OPTICAL INTENSITY MODULATOR ELECTRODE
14
OPTICAL PHASE MODULATOR ELECTRODE
11
DFB/EA/PHASE MODULATOR INTEGRATED LIGHT SOURCE
4
SIGNAL LIGHT
DFB-LB
EA OPTICAL INTENSITY MODULATOR
OPTICAL PHASE MODULATOR

FIG. 12

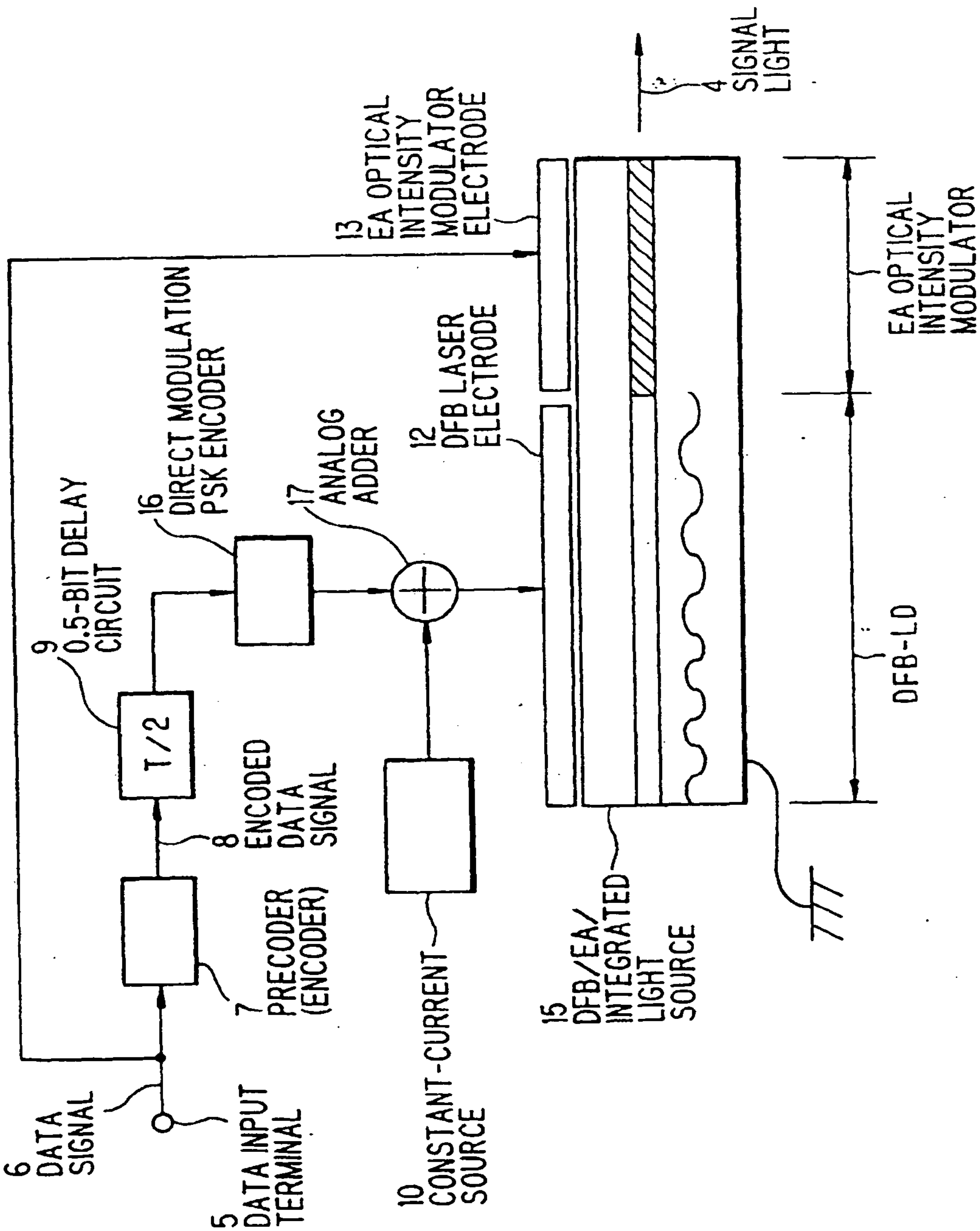

6 DATA SIGNAL
5 DATA INPUT TERMINAL
7 PRECODER (ENCODER)
8 ENCODED DATA SIGNAL
T/2
9 0.5-BIT DELAY CIRCUIT
16 DIRECT MODULATION PSK ENCODER
17 ANALOG ADDER
10 CONSTANT-CURRENT SOURCE
12 DFB LASER ELECTRODE
13 EA OPTICAL INTENSITY MODULATOR ELECTRODE
15 DFB/EA/INTEGRATED LIGHT SOURCE
4 SIGNAL LIGHT
EA OPTICAL INTENSITY MODULATOR
DFB-LD

FIG. 13

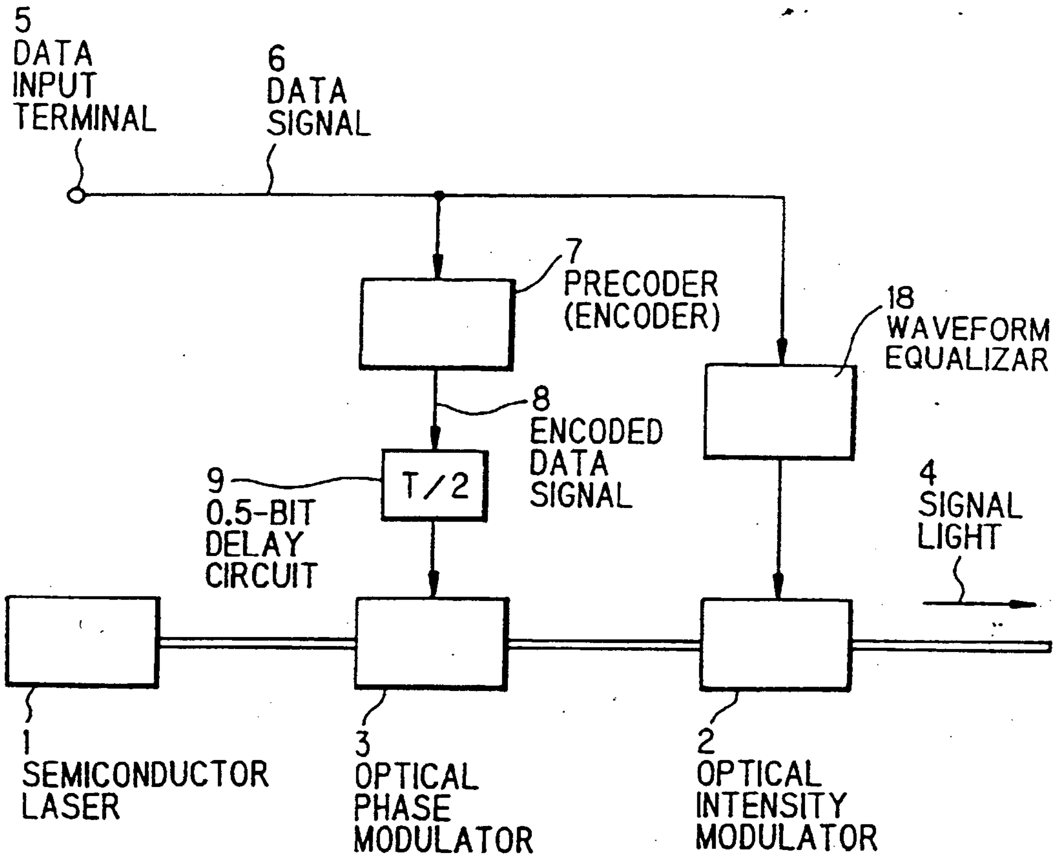

5
DATA
INPUT
TERMINAL
6
DATA
SIGNAL
7
PRECODER
(ENCODER)
18
WAVEFORM
EQUALIZAR
8
ENCODED
DATA
SIGNAL
9
0.5-BIT
DELAY
CIRCUIT
T/2
4
SIGNAL
LIGHT
1
SEMICONDUCTOR
LASER
3
OPTICAL
PHASE
MODULATOR
2
OPTICAL
INTENSITY
MODULATOR

FIG. 14

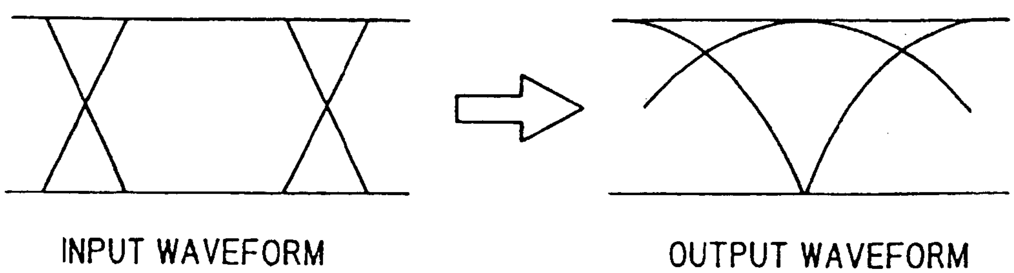

INPUT WAVEFORM
OUTPUT WAVEFORM

FIG. 15

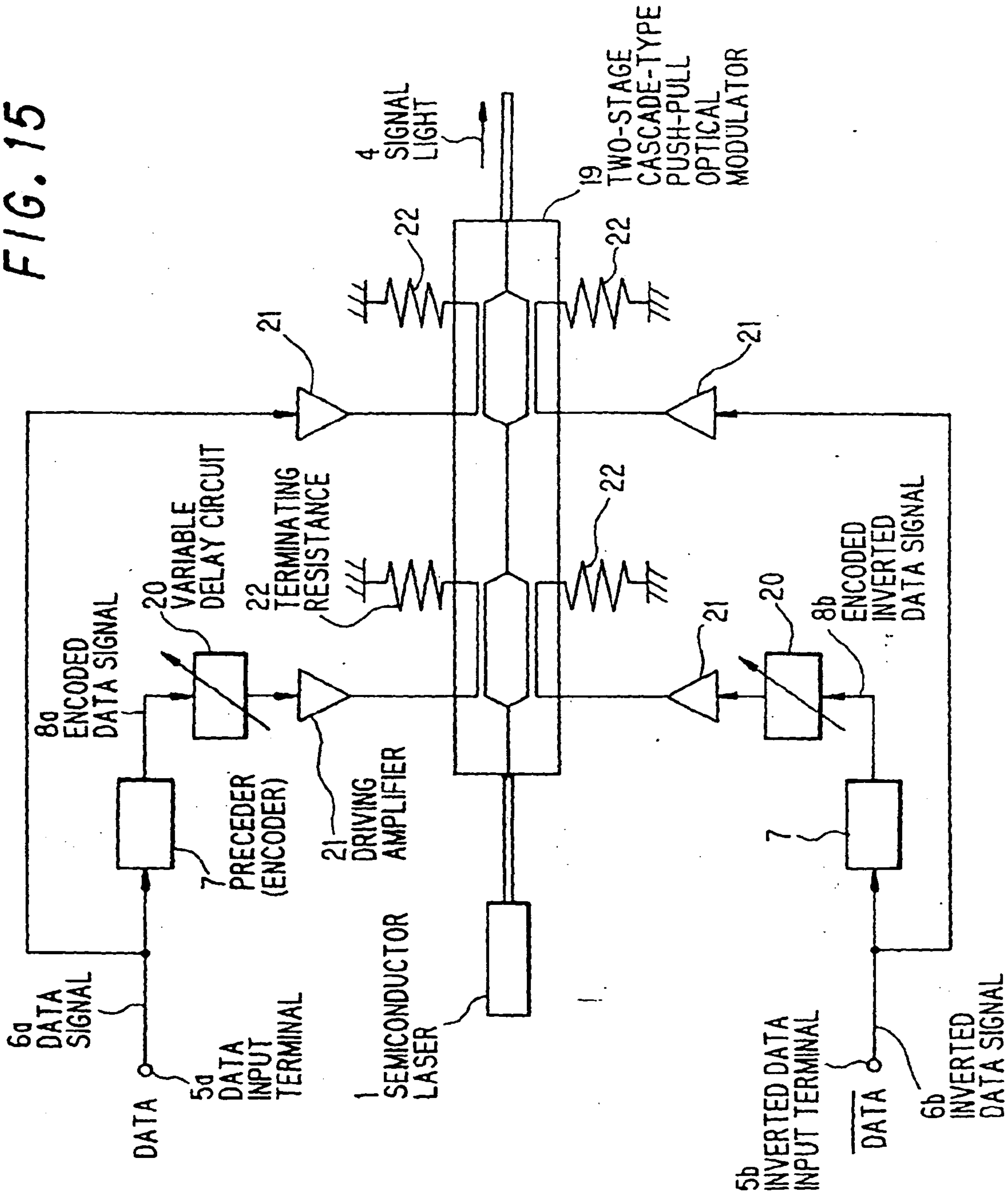

DATA
5a DATA INPUT TERMINAL
6a DATA SIGNAL
7 PRECEDER (ENCODER)
8a ENCODED DATA SIGNAL
20 VARIABLE DELAY CIRCUIT
22 TERMINATING RESISTANCE
21 DRIVING AMPLIFIER
1 SEMICONDUCTOR LASER
21
22
22
21
19 TWO-STAGE CASCADE-TYPE PUSH-PULL OPTICAL MODULATOR
4 SIGNAL LIGHT
22
22
21
20
8b ENCODED INVERTED DATA SIGNAL
7
5b INVERTED DATA INPUT TERMINAL
$\overline{\text{DATA}}$
6b INVERTED DATA SIGNAL

FIG. 16

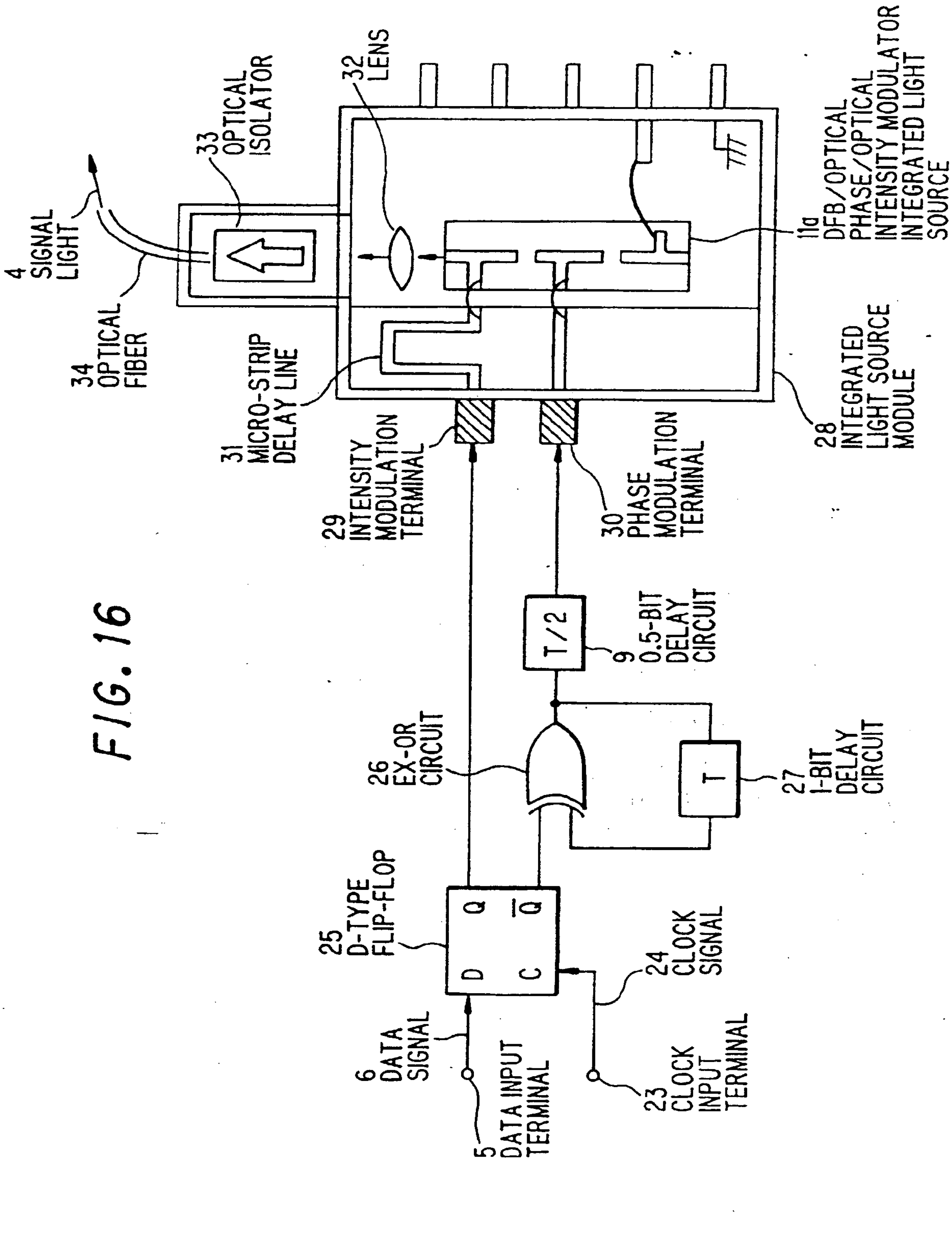

4 SIGNAL LIGHT
33 OPTICAL ISOLATOR
32 LENS
34 OPTICAL FIBER
31 MICRO-STRIP DELAY LINE
11a DFB/OPTICAL PHASE/OPTICAL INTENSITY MODULATOR INTEGRATED LIGHT SOURCE
28 INTEGRATED LIGHT SOURCE MODULE
29 INTENSITY MODULATION TERMINAL
30 PHASE MODULATION TERMINAL
T/2
9 0.5-BIT DELAY CIRCUIT
26 EX-OR CIRCUIT
T
27 1-BIT DELAY CIRCUIT
25 D-TYPE FLIP-FLOP
D
C
Q
$\overline{Q}$
24 CLOCK SIGNAL
6 DATA SIGNAL
5 DATA INPUT TERMINAL
23 CLOCK INPUT TERMINAL

FIG. 17

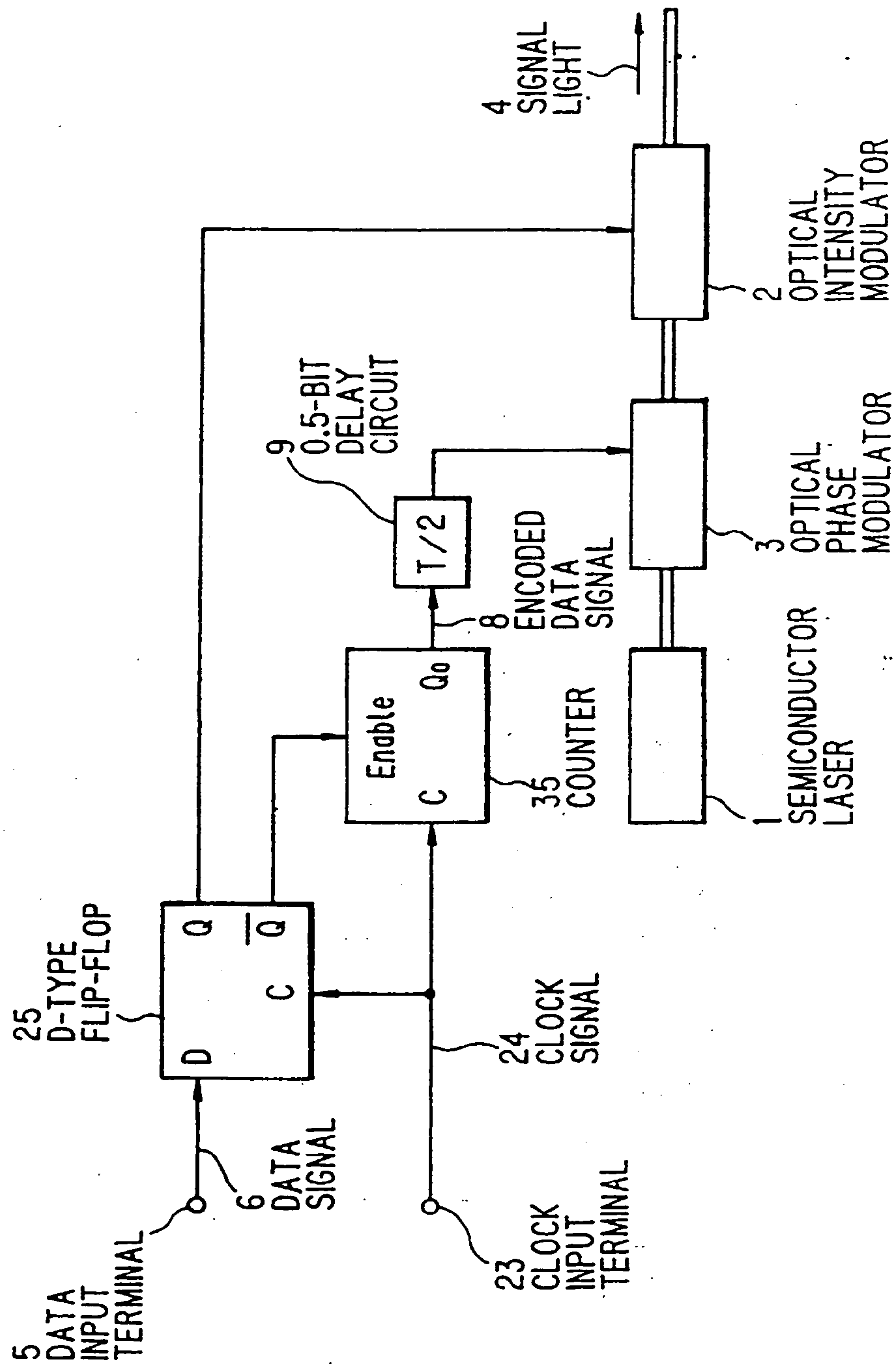

5 DATA INPUT TERMINAL
6 DATA SIGNAL
25 D-TYPE FLIP-FLOP
D
C
Q
$\overline{Q}$
23 CLOCK INPUT TERMINAL
24 CLOCK SIGNAL
Enable
C
Qo
35 COUNTER
8 ENCODED DATA SIGNAL
T/2
9 0.5-BIT DELAY CIRCUIT
1 SEMICONDUCTOR LASER
3 OPTICAL PHASE MODULATOR
2 OPTICAL INTENSITY MODULATOR
4 SIGNAL LIGHT

FIG. 18

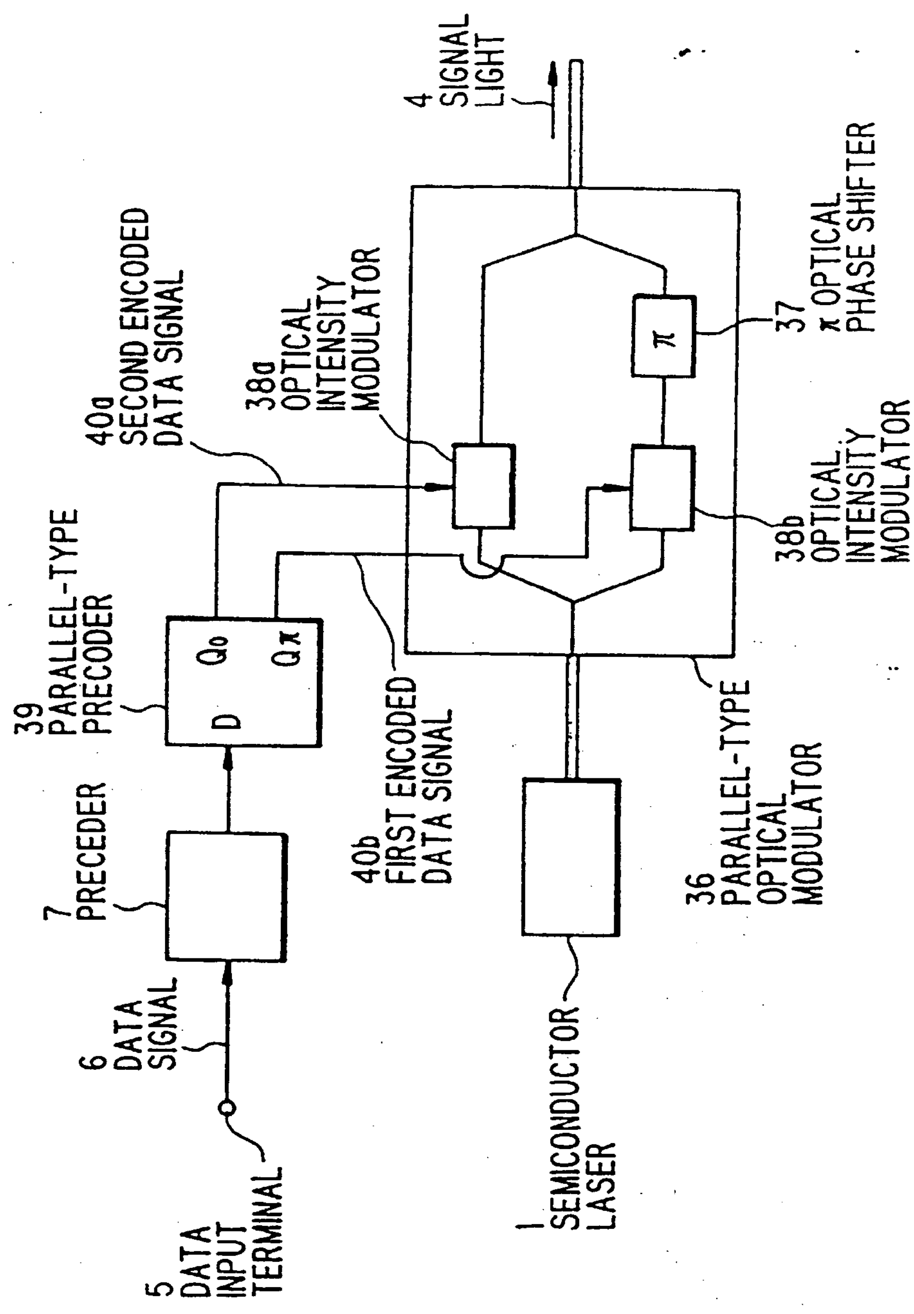

4 SIGNAL LIGHT
40a SECOND ENCODED DATA SIGNAL
38a OPTICAL INTENSITY MODULATOR
37 π OPTICAL PHASE SHIFTER
π
39 PARALLEL-TYPE PRECODER
D
Q0
Qπ
38b OPTICAL INTENSITY MODULATOR
7 PRECEDER
40b FIRST ENCODED DATA SIGNAL
36 PARALLEL-TYPE OPTICAL MODULATOR
6 DATA SIGNAL
5 DATA INPUT TERMINAL
1 SEMICONDUCTOR LASER

FIG. 19

INPUT DATA SIGNAL 6 D(i)	INPUT DATA SIGNAL 6 1-BIT BEFORE D(i−1)	MAPPING TO THREE-LEVEL D(i)+D(i−1)	OUTPUT DATA SIGNAL 40a (Q_0)	OUTPUT DATA SIGNAL 40b (Q_π)
0	0 →	0	0	1
	1 →	1	0	0
1	0 →	1	1	1
	1 →	2	1	0

$Q_0 = D(i)$, $Q_\pi = \overline{D(i-1)}$.

FIG.20

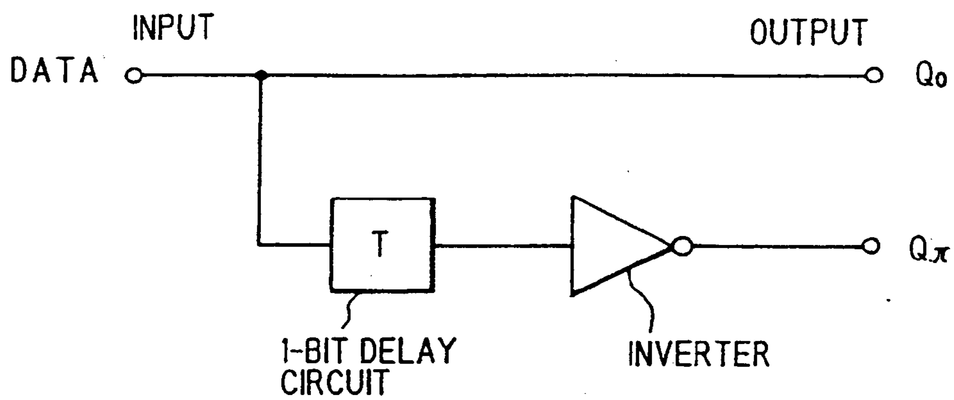

INPUT
DATA
OUTPUT
Q_0
T
Q_π
1-BIT DELAY CIRCUIT
INVERTER

FIG.21

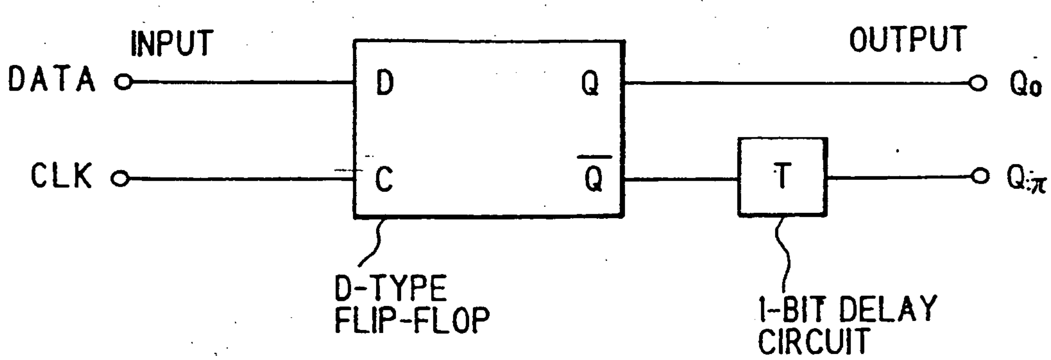

INPUT
DATA
CLK
D
C
Q
$\overline{Q}$
OUTPUT
Q_0
T
Q_π
D-TYPE FLIP-FLOP
1-BIT DELAY CIRCUIT

FIG.22

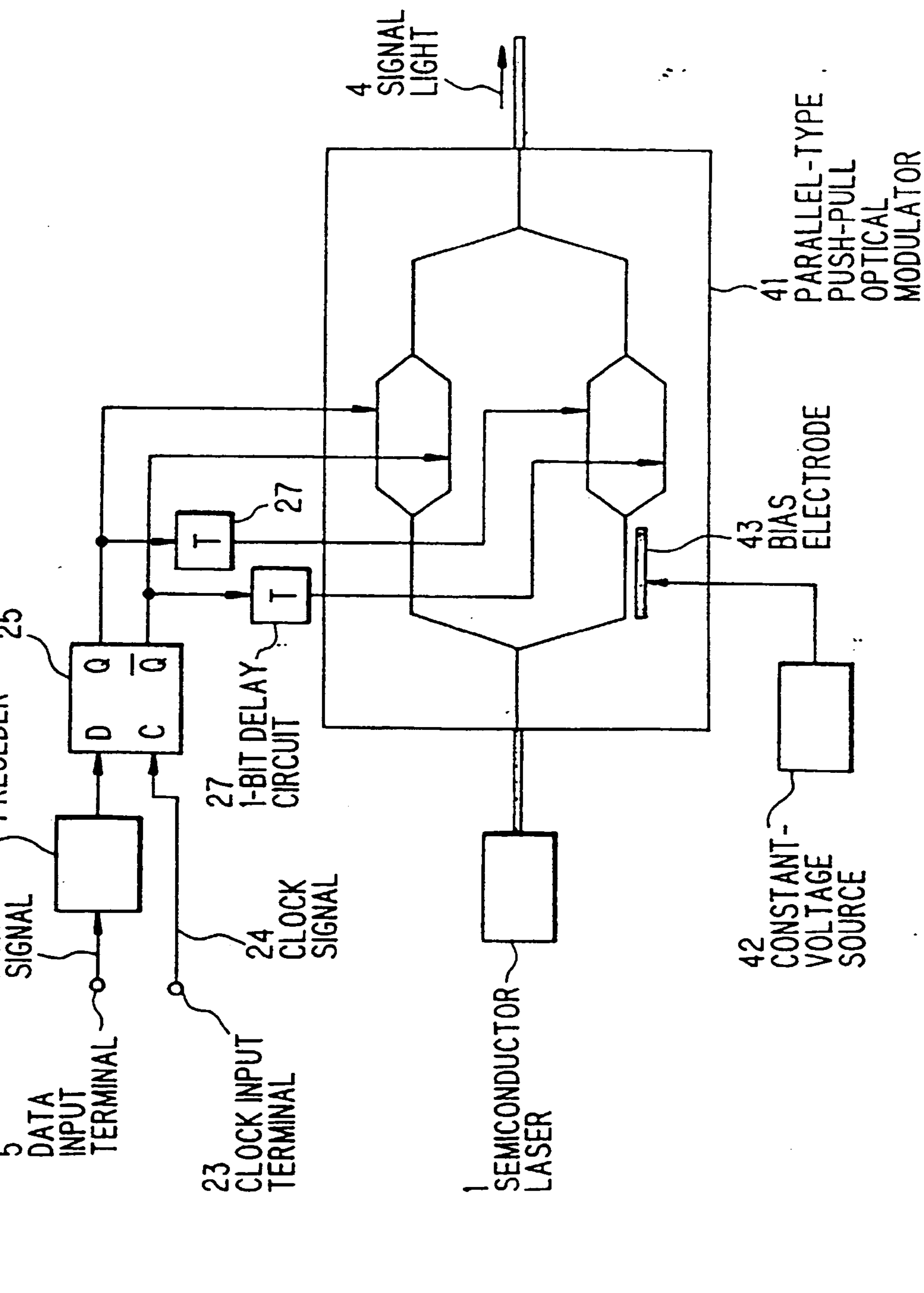
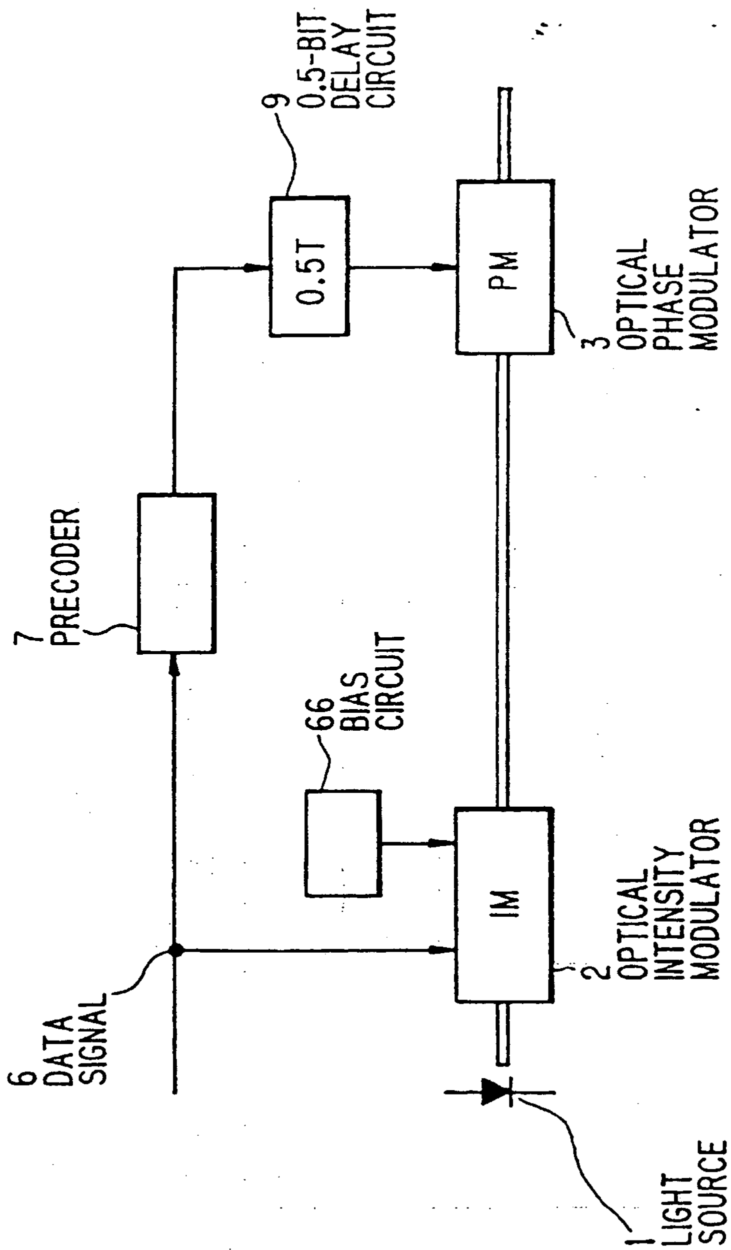

4 SIGNAL LIGHT
41 PARALLEL-TYPE PUSH-PULL OPTICAL MODULATOR
43 BIAS ELECTRODE
27
T
T
25
D Q
C $\overline{Q}$
7 PRECEDER
6 DATA SIGNAL
24 CLOCK SIGNAL
27 1-BIT DELAY CIRCUIT
5 DATA INPUT TERMINAL
23 CLOCK INPUT TERMINAL
1 SEMICONDUCTOR LASER
42 CONSTANT-VOLTAGE SOURCE

FIG. 23



6 DATA SIGNAL
7 PRECODER
0.5T
9 0.5-BIT DELAY CIRCUIT
66 BIAS CIRCUIT
IM
PM
1 LIGHT SOURCE
2 OPTICAL INTENSITY MODULATOR
3 OPTICAL PHASE MODULATOR

FIG.24A

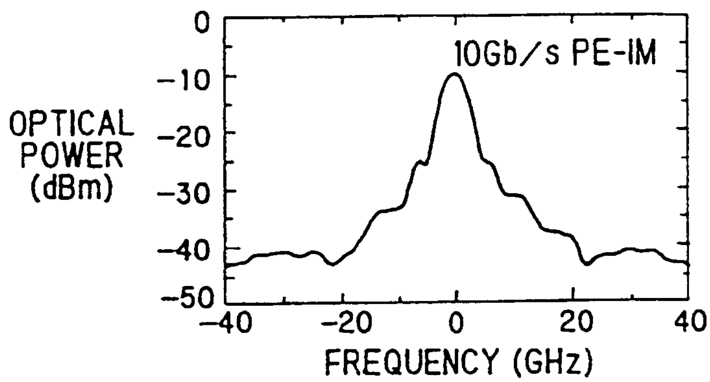


FIG.24B

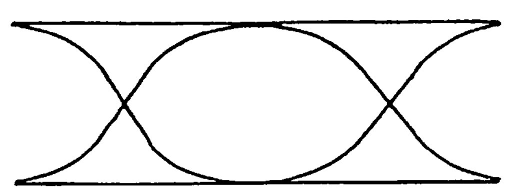


FIG.25A

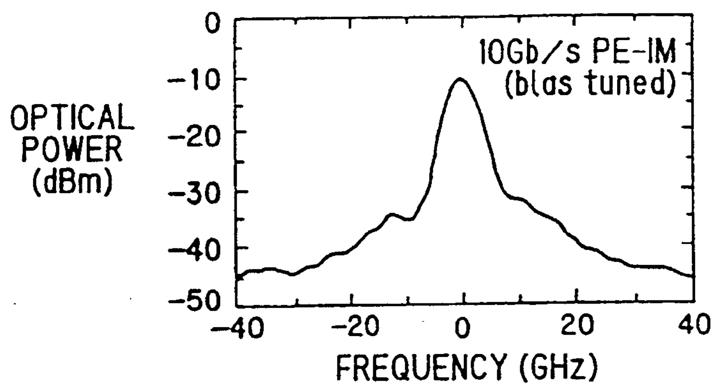


FIG.25B

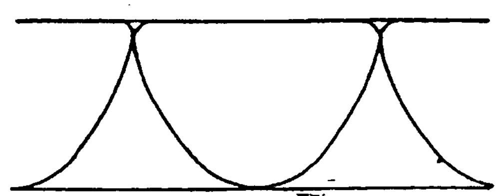


FIG. 26

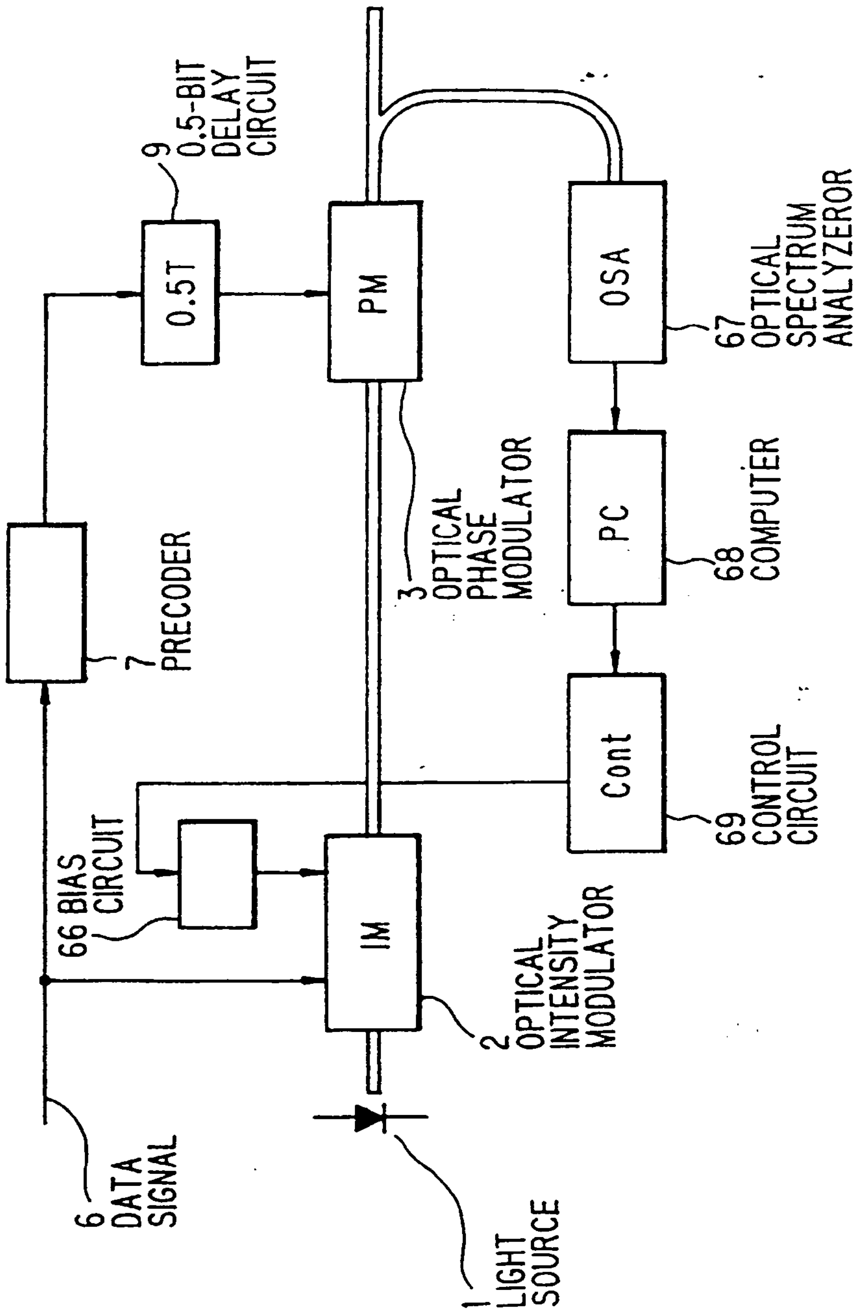

9 0.5-BIT DELAY CIRCUIT
0.5T
PM
OSA
67 OPTICAL SPECTRUM ANALYZEROR
PRECODER
7 PRECODER
3 OPTICAL PHASE MODULATOR
PC
68 COMPUTER
Cont
69 CONTROL CIRCUIT
66 BIAS CIRCUIT
IM
2 OPTICAL INTENSITY MODULATOR
6 DATA SIGNAL
1 LIGHT SOURCE

FIG.27

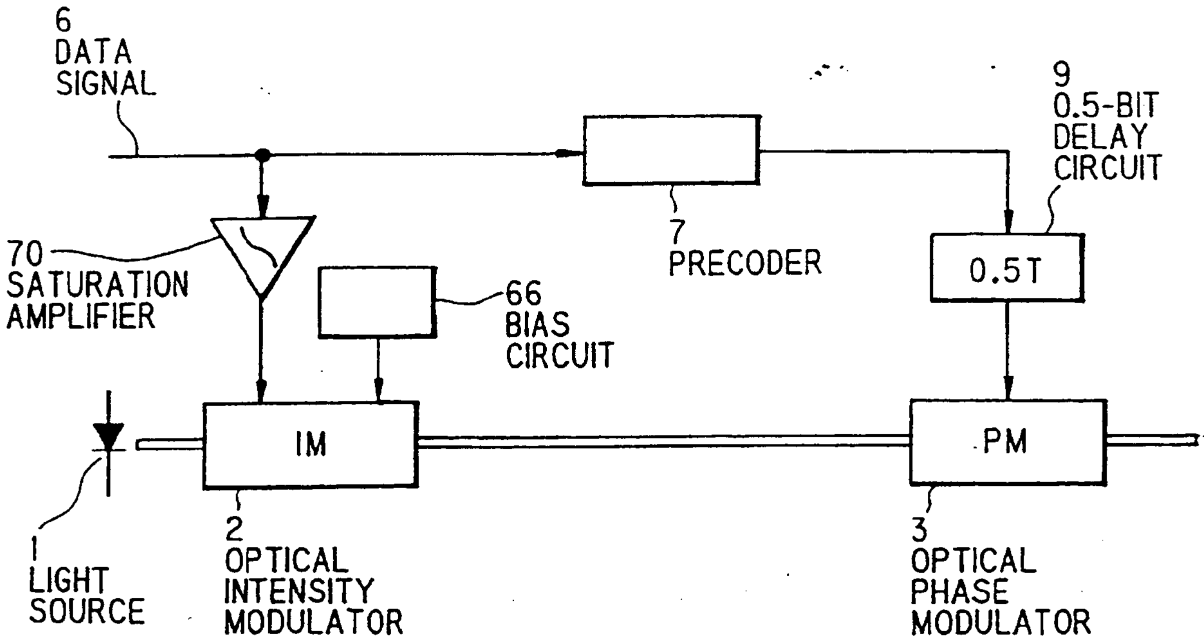

6
DATA
SIGNAL
7
PRECODER
9
0.5-BIT
DELAY
CIRCUIT
0.5T
70
SATURATION
AMPLIFIER
66
BIAS
CIRCUIT
IM
PM
1
LIGHT
SOURCE
2
OPTICAL
INTENSITY
MODULATOR
3
OPTICAL
PHASE
MODULATOR

FIG.28

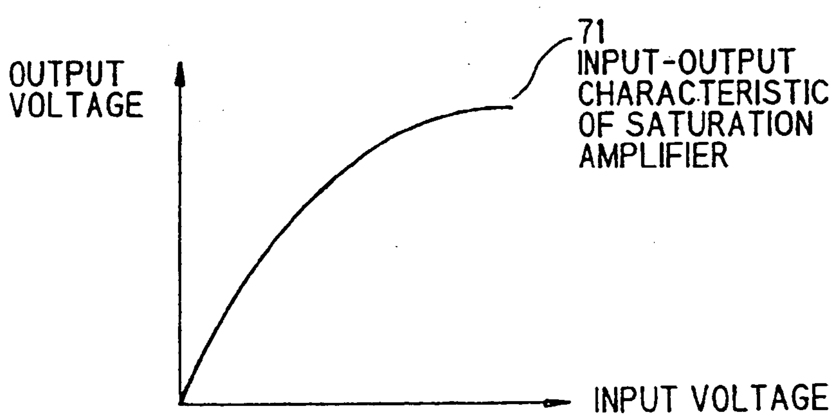

OUTPUT
VOLTAGE
71
INPUT-OUTPUT
CHARACTERISTIC
OF SATURATION
AMPLIFIER
INPUT VOLTAGE

FIG.29A

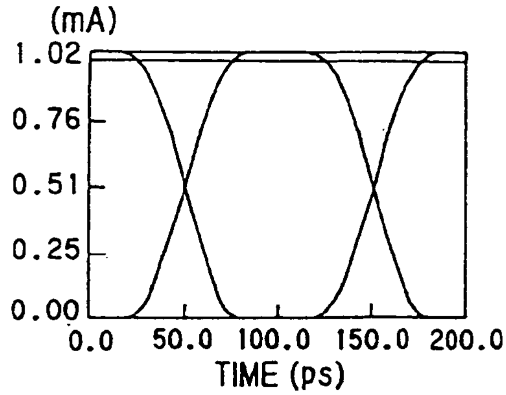


FIG.29B

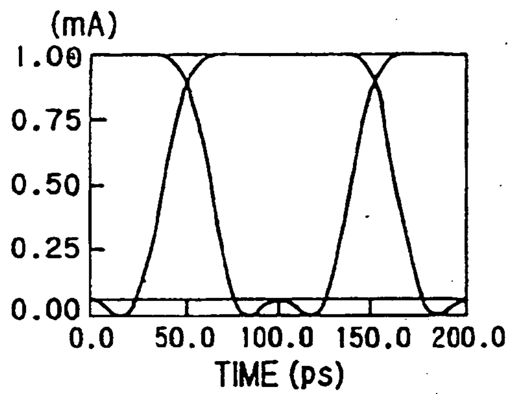


FIG.29C

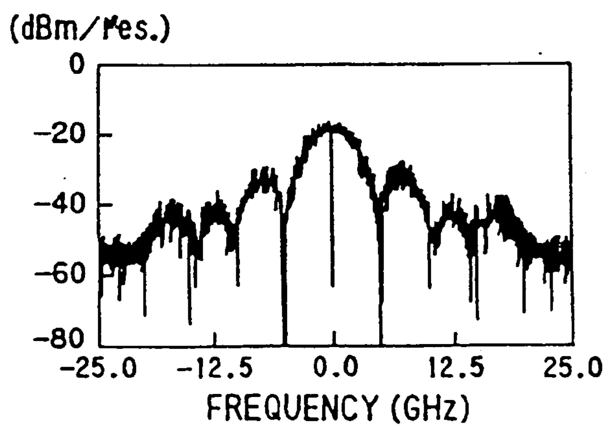


FIG.30

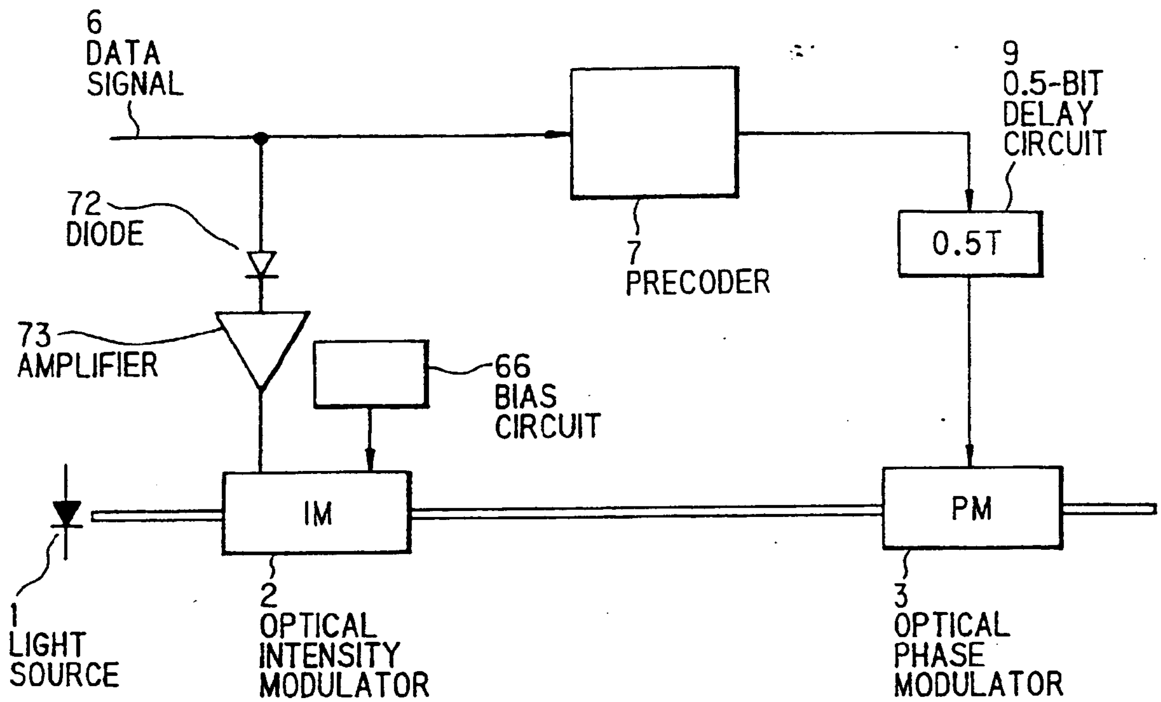

6
DATA
SIGNAL
72
DIODE
73
AMPLIFIER
7
PRECODER
9
0.5-BIT
DELAY
CIRCUIT
0.5T
66
BIAS
CIRCUIT
IM
PM
1
LIGHT
SOURCE
2
OPTICAL
INTENSITY
MODULATOR
3
OPTICAL
PHASE
MODULATOR

FIG.31

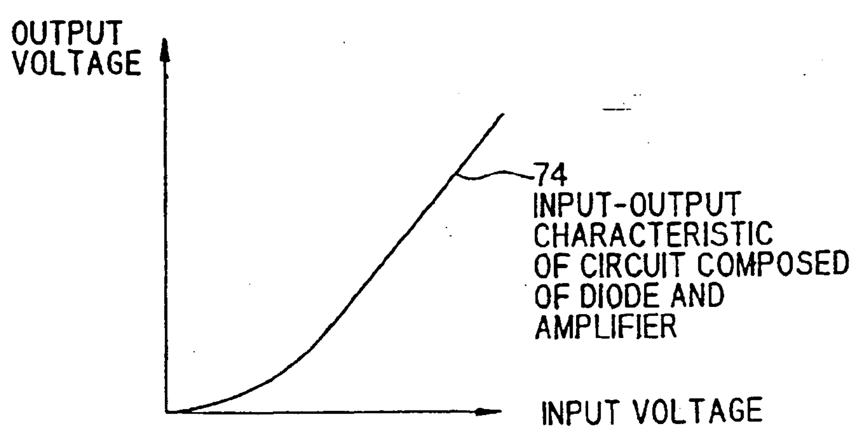
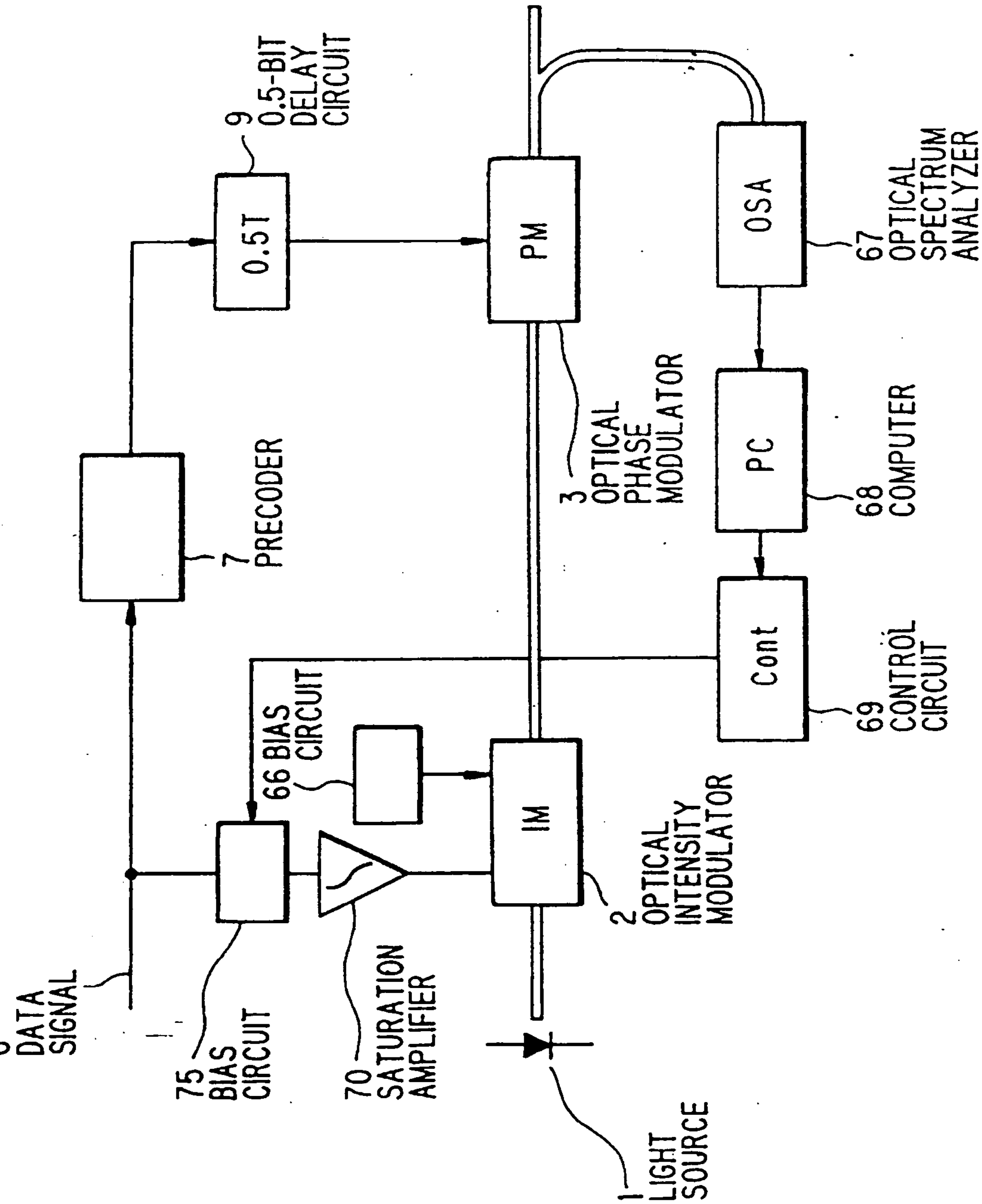
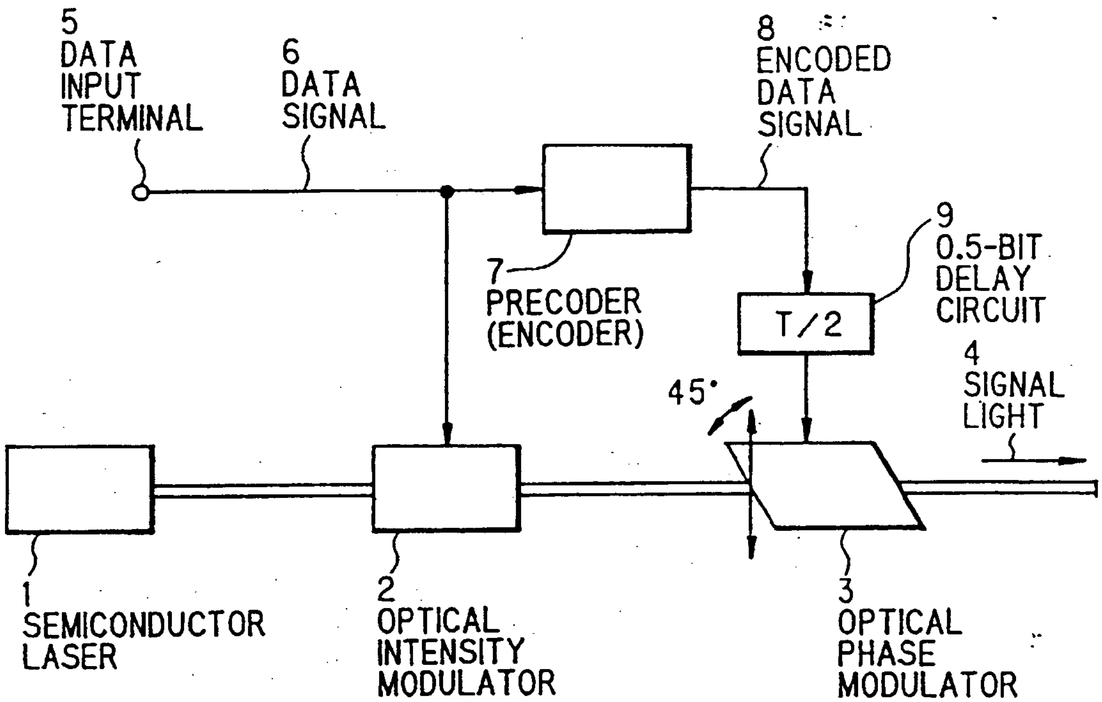

OUTPUT
VOLTAGE
74
INPUT-OUTPUT
CHARACTERISTIC
OF CIRCUIT COMPOSED
OF DIODE AND
AMPLIFIER
INPUT VOLTAGE

FIG. 32



6 DATA SIGNAL
75 BIAS CIRCUIT
70 SATURATION AMPLIFIER
1 LIGHT SOURCE
66 BIAS CIRCUIT
2 OPTICAL INTENSITY MODULATOR
IM
7 PRECODER
0.5T
9 0.5-BIT DELAY CIRCUIT
PM
3 OPTICAL PHASE MODULATOR
OSA
67 OPTICAL SPECTRUM ANALYZER
PC
68 COMPUTER
Cont
69 CONTROL CIRCUIT

FIG.33


5
DATA
INPUT
TERMINAL
6
DATA
SIGNAL
8
ENCODED
DATA
SIGNAL
7
PRECODER
(ENCODER)
9
0.5-BIT
DELAY
CIRCUIT
T/2
45°
4
SIGNAL
LIGHT
1
SEMICONDUCTOR
LASER
2
OPTICAL
INTENSITY
MODULATOR
3
OPTICAL
PHASE
MODULATOR

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 825 733 A3

(12) **EUROPEAN PATENT APPLICATION**

(88) Date of publication A3:
28.04.1999 Bulletin 1999/17

(43) Date of publication A2:
25.02.1998 Bulletin 1998/09

(21) Application number: **97306244.1**

(22) Date of filing: **18.08.1997**

(51) Int Cl.^{6}: **H04B 10/155**, H04L 27/36, H04L 25/497

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE

(30) Priority: **16.08.1996 JP 216432/96**
14.01.1997 JP 4203/97

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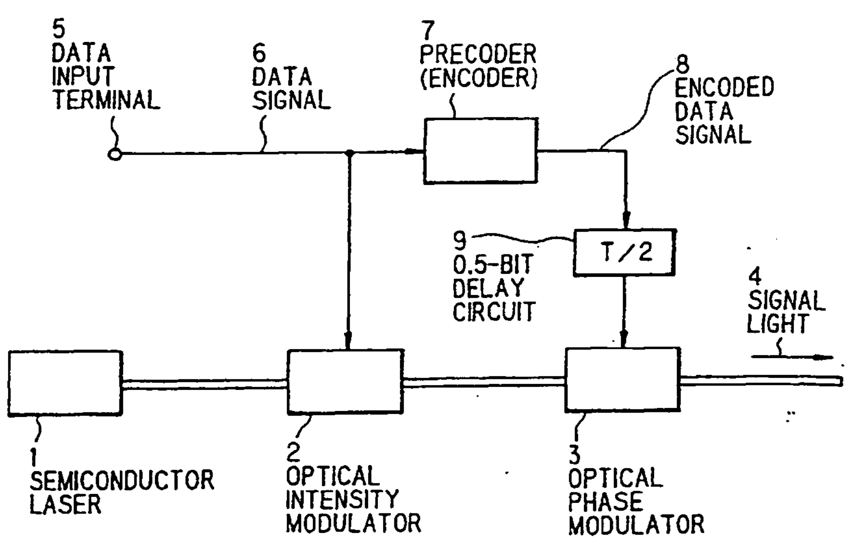
(54) **Method of generating duobinary signal and optical transmitter using the same method**

(57) Disclosed is a method for generating a duobinary signal which has the step of: modulating individually an intensity and a phase of carrier wave. Also disclosed is a duobinary-manner optical transmitter which has: a laser device which outputs signal light; an optical intensity modulator which intensity-modulates the signal light according to a first data signal generated by dividing a data signal into two signals; a precoder which inputs a second data signal generated by dividing the date signal into two signals; and an optical phase modulator which phase-modulates the intensity-modulated signal light according to a signal which is obtained delaying 0.5 bit an output signal of the precoder.

FIG.8



EP 0 825 733 A3

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EUROPEAN SEARCH REPORT

Application Number
EP 97 30 6244

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 098, no. 001, 30 January 1998 & JP 09 236781 A (NIPPON TELEGR &TELEPH CORP <NTT>), 9 September 1997	1,3	H04B10/155 H04L27/36 H04L25/497
A	* abstract *	2,4,9	
D,X	EP 0 701 338 A (NIPPON TELEGRAPH & TELEPHONE) 13 March 1996 * abstract * * page 7, line 11 - line 23 *	1,3	
A	* figures 11A,12 *	4-24	
A	US 5 008 957 A (KIYONO MIKIO) 16 April 1991 * the whole document *	11-13	
A	EP 0 565 035 A (HITACHI LTD) 13 October 1993 * abstract * * column 16, line 9 - line 30 * * figures 5,6,14 *	1-4,9, 11-13	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

H04B
H04L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	3 March 1999	Ribbe, A

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